

Harmony Gold Mining Company Limited: Harmony Free State Operations

Joel Operation

DRAFT INTEGRATED WATER AND WASTE MANAGEMENT PLAN IN SUPPORT OF THE WATER USE LICENCE APPLICATION

21 October 2025

Report Preparation By

Kongiwe Environmental (Pty) Ltd	
Registration Number	2016/135562/07
Telephone Number	+27 (10) 140 6508
Email	info@kongiwe.com
Registered Address	150 Bryanston Drive, Bryanston, Sandton, 2191, South Africa
Mailing Address	PostNet Suite No 163, Private Bag X21, Bryanston, 2021, South Africa
Website	www.kongiwe.com

Report Information

Project	Harmony Gold Mining Company Limited - Joel Operations
Report Title	Integrated Water and Waste Management Plan in Support of the Water Use Licence Application
Client	Harmony Gold Mining Company Limited
Project No.	HARM#010
Compilation Date	07 November 2025
Status of Report	Draft

Approval

Verification	Capacity	Name	Signature	Date
By Author	Environmental Intern	Iviwe Walaza		07 November 2025
Reviewed by	Senior Environmental Consultant	Phumla Mngwengwe		21 October 2025
Reviewed and Approved by	Chief Operating Officer	Grant Cornish-Bowden		29 October 2025

Please consider the Environment before you print this document.

Copyright © 2025 Kongiwe Environmental (Pty) Ltd

All rights reserved. No part of this report may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written consent of Kongiwe Environmental (Pty) Ltd. All content and methodologies remain intellectual property of Kongiwe Environmental (Pty) Ltd. Where applicable, the contents of this document are confidential and protected by legal privilege and must not be distributed to other parties without prior written permission.

This report is to be used for the sole purpose intended and should not be used for any other purpose without prior written permission.

Executive Summary

Harmony Gold Mining Company Limited – Joel Operation is applying for a Water Use Licence (WUL) to authorise the identified Section 21 (a), (b), (f), (g), (j), (c) and (i) water uses associated with the operations. The Joel Operation, forming part of the Free State Operations, is owned by Harmony Gold Mining Company Limited (Harmony). Water permits/exemption permits for various water uses associated with the Joel Operations were issued by DWS (then the Department of Water Affairs and Forestry (DWAF)), under the old Water Act, Act 54 of 1956.

Harmony Gold Mining Company ("Harmony") intends to licence its existing water uses in terms of the National Water Act, 1998 (Act No. 36 of 1998) (NWA). This Integrated Water and Waste Management Plan (IWWMP) has been compiled to support the Water Use Licence Application (WULA), related to the Joel Operations, for the existing Section 21 (a), (b), (f), (g), (j), (c) and (i) water uses in terms of the NWA.

Project Description

A description of the current operations is provided in Table 1-1 below.

Table 1-1: Current Operations at Joel Operation

Aspect	Method / System
Mining	
Underground mining	• Mining at the Joel Operation is undertaken at Joel 1 North and Joel 3 South shafts. • The total run of mine volume is provided by underground mining. • The Beatrix Reef and VS5 Reef are mined. • Mining depths are currently approximately 1 492 m below ground level.
Beneficiation	
Metallurgical plant	• Mined ore is processed at the Harmony One Plant. • Joel Plant is currently not operational (under care & maintenance). • Gold is smelted at Rand Refinery. • Tailings from the Joel Plant were disposed at the Joel Tailings Storage Facility (TSF) Complex. However, the TSF is now dormant.
Water and Waste Management Systems	
Water supply	• The Joel Operation receives water supply from Vaal Central Water, and this water is used for domestic purposes, and supplements mining and metallurgical purposes.
Dirty (waste) water containment	• Dirty water (process water) is contained in Return Water Dams. • Dirty water runoff from the shafts and processing areas is contained in Return Water Dams. • Water from the dirty water containment facilities including the return water dam is reused in mining processes and/or evaporated.
Clean water diversions	• Clean water diversions are in place at the shafts, processing areas and waste storage facilities (i.e. TSF and WRD). These direct runoff from the surrounding catchment, away from the dirty areas.

© 2025 Kongiwe Environmental (Pty) Ltd

Aspect	Method / System
Waste rock	• Waste rock from the shafts is sent to the Joel South and Joel North WRD. No waste rock is currently being processed for the Joel Operations.
Tailings	• No tailings are currently being transported, the plant is not operational.
Domestic and industrial waste	• Standard operating procedures have been developed for waste management at the Joel Operation. • Domestic waste generated at the Joel Operation is taken off-site to a registered landfill site. • Industrial waste is handled at the shaft and processing areas in designated waste handling areas. Scrap metal, wood and plastic are recycled through the Salvage Yard. • Hazardous waste is handled by the appointed contractor, currently Mico Trading, and is transported off-site to a registered hazardous waste facility.
Sewage	• Sewage effluent at the Joel Operation is handled at the Joel Sewage Treatment Plant. • Treated sewage effluent is discharged into the Theronspruit.
Surface Infrastructure	
General infrastructure	The support infrastructure associated with the Joel Operation includes: • Administration offices; • Change houses; • Engineering workshops; • Salvage yard; and • Hostels.

Water Uses

The Section 21 (a), (b), (f), (g), (j), (c) and (i) water uses requiring authorisation are presented in Table 1-2.

© 2025 Kongiwe Environmental (Pty) Ltd

Table 1-2: Section 21 Current Water Uses at the Joel Operation

ID	Source / Infrastructure	Purpose / Description	Properties	Coordinates
J_A1	Joel 3 South Shaft	Reuse of water removed from underground for the continuation of mining	Leeuwfontein 256 RD, RE	28° 16' 34.96" S 26° 48' 48.45" E
J_B1	Joel Stormwater Dam	Process water dam containing stormwater runoff	Leeuwfontein 256 RD, RE	28° 16' 22.18" S 26° 48' 54.03" E
J_F1	Joel Sewage Plant	Discharge of treated sewage effluent into the Theronspruit	Leeuwbult 580 RD, RE	28° 14' 45.21" S 26° 49' 23.03" E
J_G1	Joel Evaporation Dams	Excess water from the shafts and return water dam (emergency use only)	Leeuwfontein 256 RD, RE	28° 16' 29.35" S 26° 49' 37.66" E
J_G2	Joel 3 South Shaft TK1 Water Tank	Contains water abstracted from underground	Leeuwbult 580 RD, RE	28° 16' 34.64" S 26° 48' 43.64" E
J_G3	Joel Sewage Plant	Sewage treatment plant	Leeuwbult 580 RD, RE	28° 14' 44.46" S 26° 49' 28.79" E
J_G4	Joel 3 South (Taung South) Shaft Waste Rock Dump	Waste rock dump (dormant)	Leeuwfontein 256 RD, RE	28° 16' 37.12" S 26° 49' 09.55" E
J_G5	Joel Slime Dam Complex	Tailings storage facility (dormant)	Leeuwfontein 256 RD, RE	28° 16' 22.28" S 26° 50' 08.07" E
J_G6	Joel Return Water Dam	Return Water Dam	Leeuwfontein 256 RD, RE	28° 15' 57.78" S 26° 50' 14.86" E

© 2025 Kongiwe Environmental (Pty) Ltd

ID	Source / Infrastructure	Purpose / Description	Properties	Coordinates
J_G7	Settler Dams	Mud storage area	Leeuwfontein 256 RD, RE	28° 16' 25.98" S 26° 48' 44.82" E
J_J1	Joel 3 South Shaft	Reuse of water removed from underground for efficient continuation of underground workings	Leeuwfontein 256 RD, RE	28° 16' 34.96" S 26° 48' 48.45" E
1	Joel 3 South (Taung South) Shaft and associated pipelines	The operation and rehabilitation of the Joel 3 South (Taung South) Shaft, associated pipelines, and shaft related infrastructure within a 500 m wetland buffer.	Portion 0 (RE) of Leeuwfontein 256 RD	Start: 28° 16' 23.84" S 26° 49' 54.38" E End: 28° 16' 36.11" S 26° 50' 21.23" E
2	Joel 1 North (Taung North) Shaft & Metallurgical Plant and associated pipelines	The operation and rehabilitation of Joel 1 North (Taung North) Shaft and Metallurgical Plant, its associated pipelines, and related infrastructure within a 500 m wetland buffer.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 16' 23.84" S 26° 49' 54.38" E End: 28° 16' 36.11" S 26° 50' 21.23" E
3	Joel 1 North (Taung North) Shaft Waste Rock Dump (Dormant)	The rehabilitation of the Joel 1 North (Taung North) Shaft Waste Rock Dump within a 500 m wetland buffer.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 15' 12.69" S 26° 49' 46.51" E

© 2025 Kongiwe Environmental (Pty) Ltd

ID	Source / Infrastructure	Purpose / Description	Properties	Coordinates
				End: 28° 15' 12.69" S 26° 49' 46.51" E
4	Joel Sewage Plant	The operation and rehabilitation of the Joel Sewage Plant within a 500 m wetland buffer and its associated tributaries.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 16' 23.84" S 26° 49' 54.38" E
				End: 28° 16' 36.11" S 26° 50' 21.23" E
5	Joel Hostel Area	The operation and rehabilitation of pipelines transporting potable water within a 500 m wetland buffer and its associated tributaries.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 15' 33.59" S 26° 48' 50.33" E
				End: 28° 15' 33.85" S 26° 49' 8.65" E
6	Potable Water Pipeline Buffer Crossing 1	The rehabilitation of pipelines transporting potable water within a 500 m wetland buffer and its associated tributaries.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 15' 58.965" S 26° 48' 3.338" E

© 2025 Kongiwe Environmental (Pty) Ltd

ID	Source / Infrastructure	Purpose / Description	Properties	Coordinates
				End: 28° 15' 59.478" S 26° 48' 24.024" E
7	Potable Water Pipeline Wetland Crossing 1	The rehabilitation of pipelines transporting potable water within a wetland and 1:100 year flood line.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 15' 59.478" S 26° 48' 24.024" E
				End: 28° 15' 59.906" S 26° 48' 47.785" E
8	Potable Water Pipeline Buffer Crossing 2	The rehabilitation of pipelines transporting potable water within a 500 m wetland buffer and its associated tributaries.	10 Start: Portion 0 (RE) of Leeuwbult 580 RD 10 End: Portion 0 (RE) of Leeuwfontein 256 RD	Start: 28° 15' 59.906" S 26° 48' 47.785" E
				End: 28° 16' 0.242" S 26° 49' 6.211" E
9	Return Water Pipeline Wetland Crossing 1	The rehabilitation of pipelines transporting return water within a wetland and its associated tributaries.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 14' 47.115" S 26° 49' 30.303" E

© 2025 Kongiwe Environmental (Pty) Ltd

ID	Source / Infrastructure	Purpose / Description	Properties	Coordinates
				End: 28° 14' 58.936" S 26° 49' 17.762" E
10	Return Water Pipeline Buffer Crossing 1	The rehabilitation of pipelines transporting return water within a 500 m wetland buffer and its associated tributaries.	12 Start: Portion 0 (RE) of Leeuwbult 580 RD 12 End: Portion 0 (RE) of Leeuwfontein 256 RD	Start: 28° 14' 58.936" S 26° 49' 17.762" E
				End: 28° 16' 29.453" S 26° 48' 47.480" E

© 2025 Kongiwe Environmental (Pty) Ltd

Exemptions

The Regulation GN704 (GN R704, Gazette No. 20119, 1999) exemptions required to be authorised are presented in Table 1-3.

Table 1-3: Regulation 704 Exemptions for Joel Operations

Activity	Applicable GN 704 regulations	Motivation / Reason for Exemption
The operation and rehabilitation of the Joel Stormwater Dam within a 500 m wetland buffer.	**Regulation 6: Capacity requirements of clean and dirty water systems** 6(c): Capacity requirements of clean and dirty water systems 6(d): Design, construct, maintain and operate any dirty water system at the mine or activity so that it is not likely to spill into any clean water system more than once in 50 years. **Regulation 7: Protection of water resources** 7(a): prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act.	The facility is present on Landsat imagery that pre-dates June 1999 when GN R704 was enacted, and therefore it is likely that this dam was already being used to contain dirty water.
The operation and rehabilitation of the Joel 1 North (Taung North) Shaft Waste Rock Dump within a 500 m wetland buffer.	**Regulation 6: Capacity requirements of clean and dirty water systems** 6(c): Capacity requirements of clean and dirty water systems **Regulation 7: Protection of water resources** 7(a): prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act.	The facilities are present on aerial imagery that pre-dates GN R704.
The operation and rehabilitation of the Joel Evaporation Dam within a 500 m wetland buffer and 100 m stream buffer.	**Regulation 6: Capacity requirements of clean and dirty water systems** 6(c): Capacity requirements of clean and dirty water systems **Regulation 7: Protection of water resources** 7(a): prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act.	The facility is present on aerial imagery that pre-dates GN R704.
The reclamation and rehabilitation of the Joel TSF Complex, and operation and rehabilitation of the associated pipelines within a 500 m wetland buffer.	**Regulation 6: Capacity requirements of clean and dirty water systems** 6(c): Capacity requirements of clean and dirty water systems **Regulation 7: Protection of water resources** 7(a): prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act. **Regulation 4: Restrictions on locality** 4(a): locate or place any residue deposit, dam, reservoir, together with any associated structure or any other facility within the 1:100-year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, borehole or well, excluding boreholes or wells drilled specifically to monitor the pollution of groundwater, or on water-logged ground, or on ground likely to become water-logged, undermined, unstable or cracked	The facilities are present on aerial imagery that pre-dates GN R704.
The operation and rehabilitation of the Joel North and South Waste Rock Dumps	**Regulation 6: Capacity requirements of clean and dirty water systems** 6(c): Capacity requirements of clean and dirty water systems **Regulation 7: Protection of water resources** 7(a): prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act.	The facilities are present on aerial imagery that pre-dates GN R704.. It must be noted that a waste classification on the waste rock material at the South Waste Rock dump should be undertaken if this material is to be used for any purpose at the mine.
Shafts and mine area	**Regulation 5:** May not use any residue or substance which causes or is likely to cause pollution of water resource for the construction of any dam or other impoundment or any embankment, road or railway or for any other purpose which is likely to cause pollution of a water resource.	An exemption is required to use reclaimed waste rock from the operation's waste rock dumps to backfill decommissioned shafts for safety purposes, and as aggregate material for construction and other infrastructure. An exemption is required to use reclaimed waste rock material for the purposes of rehabilitation, minimising the unauthorized increase of the underground workings and for safety purposes.

© 2025 Kongiwe Environmental (Pty) Ltd

Action Plan

Operational Action Plans have been developed to address aspects of the water and waste management strategy that are not yet in place or requiring additional measures. The Action Plans identified for the Joel Operation are presented in Table 1-4.

Table 1-4: Operational Action Plan for the Joel Operations

Aspect	Actions	Timeframe
GN704 Audit	Conduct a GN 704 Audit.	December 2027
Metering	Ensure adequate metering is implemented for all water uses to assist with an improved water balance.	December 2027
Salt Balance	Develop a salt balance for the Joel Operation.	December 2027
Stormwater Management	Implement site specific Storm Water Management Plan for the Joel Operation.	December 2027
	Operate and maintain dam levels to prevent spillages to the clean environment.	Ongoing
Waste	Undertake a geochemical assessment to characterise the waste rock and tailings at the operations.	December 2027
	Implement and maintain waste management facilities.	Ongoing
Waste Rock	Reclaim and/or rehabilitate the remaining waste rock dumps in line with the mine closure plan (if possible).	Life of mine
	Rehabilitate footprint areas and ensure the rehabilitated areas are free draining (if possible).	Life of mine
Water Quality	Compile an annual report to interpret the surface and groundwater quality monitoring results.	Annually
	Compare water quality results to background quality, the Reserve and the WUL limits (once received).	Ongoing
Biomonitoring	Undertake yearly, seasonal biomonitoring and toxicity testing on the surrounding sensitive and impacted environments.	Once WUL is issued
Monitoring and Maintenance	Undertake continuous monitoring and maintenance of the pipelines on site.	Ongoing
Management Procedures	Ensure the continued implementation of all emergencies and spill prevention and mitigation action plans on site.	Ongoing

© 2025 Kongiwe Environmental (Pty) Ltd

Key Commitments and Recommendations

The WULA for the Joel Operation has considered the current DWS requirements. All supporting information as available is included either in the main text or as appendices to this IWWMP. It is recommended that Harmony implements the scheduled actions and recommended mitigation measures, to address any potential impacts.

© 2025 Kongiwe Environmental (Pty) Ltd

Table of Content

Executive Summary ii
Project Description ii
Water Uses iii
Exemptions ix
Key Commitments and Recommendations xi
1. Introduction 1
1.1 Activity Background 1
1.2 Regional Setting and Activity Location 1
1.3 Applicant Details 1
1.4 Property Description 2
1.5 Purpose of the IWWMP 4
2. Project Conceptualisation 4
2.1 Description of Activity 4
2.2 Extent of Activity 5
2.3 Key Activity Related Processes and Products 5
2.4 Activity Life Description 5
2.5 Activity Infrastructure Description 5
2.6 Key Water Uses and Waste Streams 9
2.6.1 Water Supply 9
2.6.2 Sewage Effluent 10
2.6.3 Stormwater Management 10
2.7 Organisational Structure of Activity 10
2.8 Business and Corporate Policies Related to the Environment 10
3. Regulatory Water and Waste Management Framework 11
3.1 Summary of all Water Uses 14
3.2 Existing Lawful Water Uses 14
3.3 Relevant Exemptions 16
3.4 Generally Authorised Water Uses 17
3.5 Previous Water Use Applications 17
3.6 New Water Uses to be Licensed 17
3.7 Waste Management Activities (NEM:WA) 24
3.8 Other Authorisations (EMPrs, EIAs, RODs, Regulations) 25
4. Present Environmental Situation 26
4.1 Climate 26
4.1.1 Regional Climate Rainfall 26
4.1.2 Evaporation 27
4.2 Topography 28
4.3 Geology 28

© 2025 Kongiwe Environmental (Pty) Ltd

4.4 Soils, Land Use and Land Capability 32
4.5 Aquatic Biodiversity 35
4.5.1 Status of Sub-quaternary Reach 35
4.5.2 Resource Quality Objectives 35
4.5.3 In situ Water Quality 36
4.5.4 Intermediate Habitat Integrity Assessment 39
4.5.5 Aquatic Macroinvertebrates 40
4.5.6 South Africa Scoring System 41
4.5.7 Macroinvertebrate Response Assessment Index (MIRAI) Results 42
4.5.8 Fish Community Assessment 42
4.5.9 Present Ecological State 43
4.6 Wetlands 44
4.6.1 Wetland Indicators 44
4.6.2 General Functional Description of Wetland Types 45
4.6.3 Wetland Delineation Within Joel Operation 46
4.7 Flora 48
4.8 Fauna 48
4.9 Surface Water 48
4.9.1 Water Management Area 49
4.9.2 Surface Water Hydrology 49
4.9.3 Surface Water Quality 49
4.9.4 Mean Annual Runoff 51
4.9.5 Floodlines 51
4.9.6 Resource Class and River Health 53
4.9.7 Reserve 53
4.9.8 Biomonitoring and Toxicity Testing 53
4.9.9 Surface Water Survey 53
4.10 Groundwater 53
4.10.1 Aquifer 53
4.10.2 Hydraulic Properties 54
4.10.3 Monitoring Borehole Positions 54
4.10.4 Groundwater Levels vs. Topography 56
4.10.5 Groundwater Level Contours 58
4.10.6 Groundwater Flow Directions 59
4.10.7 Detailed Analysis of Contamination Impact from Source Areas 60
4.11 Socio-Economic Environment 66
5. Analysis and Characterisation of Activity 67
5.1 Site Delineation for Characterisation 67
5.2 Water and Waste Management 67
5.2.1 Potable and Process Water 67

© 2025 Kongiwe Environmental (Pty) Ltd

5.3 Present Stormwater Management Measures 67
5.3.1 Existing Stormwater Measures 67
5.3.2 Clean and Dirty Areas 68
5.3.3 Proposed Stormwater Measures and Recommendations 68
5.4 Water and Salt Balance 68
5.4.1 Water Balance 68
5.4.2 Salt Balance 70
5.5 Waste 70
5.5.1 Non-Mine Residue 70
5.5.2 WRDs 71
5.5.3 TSFs 71
5.6 Operational Management 71
5.6.1 Organisational Structure 72
5.6.2 Resources and Compliance 72
5.6.3 Education and Training 72
5.6.4 Internal and External Communication 72
5.6.5 Awareness Raising 74
5.7 Monitoring and Control 74
5.7.1 Surface Water Monitoring 75
5.7.2 Biomonitoring and Toxicity Testing 75
5.7.3 Waste Monitoring 79
5.7.4 Groundwater monitoring 79
5.8 Risk and Impact Assessment / Best Practice Assessment 79
5.8.1 Risk Assessment Key 79
5.9 Unplanned Events 92
5.10 Best Practice Assessment 92
5.11 Public Participation 93
5.12 Matters Requiring Attention / Problem Statement 93
6. Water and Waste Management 93
6.1 Water and Waste Management Philosophy 93
6.2 Strategies 94
6.2.1 Water Management Strategy 94
6.2.2 Waste Management Strategy 94
6.3 Performance Objectives/ Goals 95
6.3.1 Water 95
6.3.2 Waste 96
6.4 Measures to Achieve and Sustain Performance Objectives 96
6.5 Options Analysis and Motivation for Preferred Options 96
6.6 IWWMP Action Plan 96
6.7 Control and Monitoring 97

© 2025 Kongiwe Environmental (Pty) Ltd

6.7.1 Operational Phase 97
6.7.2 Post-Closure Phase 97
6.8 Monitoring of Change in Baseline Information 98
6.9 Audit and Report on Performance Measures 98
6.10 Audit and Report on Relevance of IWWMP Action Plan 98
7. Conclusion 98
7.1 Regulatory Status of Activity 98
7.2 Statement on Water Uses requiring Authorisation, Dispensing with Licensing Requirement with possible Exemption from Regulations 98
8. References 100
9. Appendices 101

List of Tables

Table 1-1: Current Operations at Joel Operation ii
Table 1-2: Section 21 Current Water Uses at the Joel Operation iv
Table 1-3: Regulation 704 Exemptions for Joel Operations ix
Table 1-4: Operational Action Plan for the Joel Operations x
Table 1-1: Contact Details 2
Table 1-2: Property Description 2
Table 2-1: Description of the Joel Operations Mining Activities 6
Table 2-2: Potable Water Consumption for 2024 and 2025 (m^3) for Joel 1 Shaft 9
Table 2-3 Potable Water Consumption for 2024 and 2025 (m3) for Joel 3 Shaft 9
Table 2-4: Persons Responsible for Implementation of the IWWMP and Future WUL Commitments 10
Table 3-1: Water Management Legal and Regulatory Framework Requirements 11
Table 3-2: List of Permits Authorised by DWAF for the Joel Operation 15
Table 3-3: Regulation GN704 Exemptions 16
Table 3-4: Section 21 Water Uses Requiring Authorisation for the Joel Operations 18
Table 4-1: Storm Rainfall Depths for the Area 27
Table 4-2: Monthly and Annual Evaporation at the Joel Operations (2000 - 2012) 27
Table 4-3: Mean Monthly and Annual Evaporation at the Joel Operations for 2019 28
Table 4-4: Land Cover within Joel Operation 32
Table 4-5: Summary of the Present Ecological State of the SQRs Associated with the Joel Operations (DWS, 2014) 35
Table 4-6: Resource Quality Objectives for C42K 36
Table 4-7: In situ Water Quality Results for the Joel Operations (May 2022) 36
Table 4-8: Results for the Doring River Habitat Integrity Assessment 40
Table 4-9: Biotope Diversity Scores for the May 2022 Assessment Continued 40
Table 4-10: Macroinvertebrate Assessment Results Recorded for the Joel Operations 41
Table 4-11: MIRAI Score for the Sampled Systems (Main Stems) 42

© 2025 Kongiwe Environmental (Pty) Ltd

Table 4-12: Presence/ Absence of Fish Species for the Sampled Sites and Fish Response Assessment Index (FRAI) Results per Reach 43
Table 4-13: The Present Ecological Status of the Rivers Pertaining to the Harmony Free State Operations 43
Table 4-14: Surface Water Quality Monitoring Program 49
Table 4-15: Surface Water Quality Guidelines and Standards 50
Table 4-16: Peak Flows Used to Determine the Floodlines for the Joel Operations 51
Table 4-17 Joel Operation Monitoring Borehole Coordinates 55
Table 4-18 Water Levels for Monitoring Boreholes 55
Table 4-19 Joel Operation Source Description 61
Table 5-1: The Waste Management Hierarchy (Jones & Wagener, 2017) 70
Table 5-2: Harmony Incident Classification Criteria (Harmony Risk Matrix - October 2019) 71
Table 5-3: Internal Communication Procedure 73
Table 5-4: External Communication Procedure 73
Table 5-5: Environmental Complaints Process 74
Table 5-6: Recommended Monitoring Checklist for Joel Operation 77
Table 5-7: Recommended Methodology to be Applied to each Sampling Site in Future Monitoring 78
Table 5-8: Severity 79
Table 5-9: Spatial Scale 80
Table 5-10: Duration 80
Table 5-11: Frequency of the Activity 80
Table 5-12: Frequency of the Incident/ Impact 81
Table 5-13: Legal Issues 81
Table 5-14: Detection 81
Table 5-15: Significance Ratings Matrix 82
Table 5-16: Joel Operations Impact Assessment 83
Table 5-17: Scoring of Impact Severity, Spatial Scale and Duration to Determine Level of Consequence 86
Table 5-18: Aspects and Potential Impacts Relevant to the Joel Operation 88
Table 5-19: Summary of potential Unplanned Events that Require Attention 92
Table 5-20: BPGs Applicable to the Joel Operations 92
Table 6-1: Operational Action Plan for the Joel Operation 96

List of Figures

Figure 1-1: Joel Operation Locality Map 3
Figure 2-1: Joel Operation Site Infrastructure Map 8
Figure 3-1: Joel Water Use Map 23
Figure 4-1: Mean Monthly Rainfall for the Area 26
Figure 4-2 Joel Operation Topography 30
Figure 4-3 Joel Operation Geology 31
Figure 4-4 Joel Soil Classification Map 33
Figure 4-5 Joel Land Use Map 34

© 2025 Kongiwe Environmental (Pty) Ltd

Figure 4-6: pH of Each Site Associated with the Joel Operation 37
Figure 4-7: EC of Each Site Associated with the Joel Operation 38
Figure 4-8 Composite Wetland Delineation Map for the Joel Operations 47
Figure 4-9: Joel Operations and Floodlines 52
Figure 4-10 Monitoring Boreholes at Joel Operation 56
Figure 4-11 Welkom Harmony - Water Level vs Topography 57
Figure 4-12 Welkom Harmony- Depth to Water Level Frequency Distribution 58
Figure 4-13 Observed Groundwater Flow Contours 59
Figure 4-14 Groundwater Flow Directions Indicated by Black Arrows 60
Figure 4-15 Location of the Joel Operation. Sources are indicated by the Red Cross Hatched Areas 61
Figure 4-16 Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows. 62
Figure 4-17 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers) 63
Figure 4-18 Simulated mass loads to the groundwater pathway from sources. 64
Figure 4-19 Simulated cumulative mass loads to the groundwater pathway from sources. 64
Figure 4-20 Simulated mass loads from the groundwater pathway to receptors. 65
Figure 4-21 Simulated cumulative mass loads from the groundwater pathway to receptors. 65
Figure 5-1: Joel Water Balance (2025) 69
Figure 5-2: The Mitigation Hierarchy as described by the DEA (2013) 91

List of Appendices

Appendix A: Master Layout Plan 102
Appendix B: Water Resource Baseline and Risk Assessment 103
Appendix C: Public Participation Process Report 104
Appendix D: Surface Water Study 105
Appendix E: Quantity Report for September 2024 to February 2025 106
Appendix F: Groundwater Study 107

© 2025 Kongiwe Environmental (Pty) Ltd

Abbreviations and Units

Abbreviation	Description
BP	Best Practice
BPG	Best Practice Guidelines
CMS	Catchment Management Strategies
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EIA	Environmental Impact Assessment
EMPr	Environmental Management Programme
EN	Endangered
GA	General Authorisation
GN R	Government Notice Regulation
IDP	Integrated Development Plan
IWULA	Integrated Water Use Licence Application
IWWMP	Integrated Water and Waste Management Plan
LDM	Lejweleputswa District Municipality
LoM	Life of Mine
MIRAI	Macroinvertebrate Response Assessment Index
MPRDA	Mineral and Petroleum Resources Development Act (Act No. 28 of 2002)
MR	Mining Right
NEMA	National Environment Management Act (Act No. 107 of 1998)
NEM:BA	The National Environmental Management: Biodiversity Act (Act No. 10 of 2004)
NEM:WA	National Environment Management: Waste Act (Act No. 59 of 2008)
NWA	National Water Act, 1998 (Act No. 36 of 1998)
NWAA	The National Water Amendment (Act No. 27 of 2014)
NWRS	The National Water Resource Strategy
PES	Present Ecological State
REC	Recommended Ecological Category
RQO	Resource Quality Objectives
RWD	Return Water Dam
SANAS	South African National Standards
SLP	Social and Labour Plan
TSF	Tailing Storage Facility
TWQR	Target Water Quality Range
WMA	Water Management Act

© 2025 Kongiwe Environmental (Pty) Ltd

Abbreviation	Description
WUL	Water Use Licence
WULA	Water Use License Application
WRD	Waste Rock Dump
WSA	Water Services Act, 1997 (Act No 108 of 1997)

© 2025 Kongiwe Environmental (Pty) Ltd

1. Introduction

Harmony Gold Mining Company Limited – Joel Operations is applying for a Water Use Licence (WUL) to authorise the identified Section 21 (a), (b), (f), (g), (j), (c) and (i) water uses associated with the operations. This Integrated Water and Waste Management Plan (IWWMP) serves as a technical supporting document for the Water Use Licence Application (WULA) for the Harmony Gold Mining Company Joel Operations.

The main supporting documents used to develop this IWWMP include:

- 2020 Free State Operations IWWMP (SRK Consulting, August 2020).
- Environmental Management Programme (EIMS, March 2019).
- Groundwater study (AquiSim Consulting, 2025).
- Water Resource Baseline and Risk Assessment (The Biodiversity Company, July 2022).
- 2023 Surface Water Study for the Harmony Gold Mining Free State Operations NWA Section 21 (c) and (i) Water Uses Project (Hydrospatial, October 2023).

The Joel Operations, forming part of the Harmony Free State Operations, are owned by Harmony Gold Mining Company Limited (Harmony). This IWWMP has been compiled to support a new WULA for the Joel Operations for the existing Section 21 (a), (b), (f), (g), (j), (c) and (i) water uses in terms of the National Water Act, 1998 (Act No. 36 of 1998) (NWA). The WULA covers the existing activities at the Joel Operations and associated Section 21 water uses.

1.1 Activity Background

The Harmony Free State Operations have been mining in the Free State since approximately 1950, and mining at the Joel Operation was initiated during 1978. The Joel Operation consists of the Joel Plant and two shafts (Joel 1 North and Joel 3 South). Other infrastructure found at the Joel Operation includes the metallurgical plant (which processes gold), Tailings Storage Facilitity (TSF), waste rock dumps (WRDs) and a sewage treatment plant. The total mining lease area of the Joel Operation is approximately 2 161 ha.

The primary product is gold and its associated minerals (in some cases aggregate). The mining method used by the Joel Operation consist of the standard open stooping layout for extraction of narrow, generally flat dipping gold reefs occurring deeper than 500m below the surface. The operation has a planned life of mine of until at least 2029.

1.2 Regional Setting and Activity Location

The Joel Operation is located in the Free State Province within the Lejweleputswa District Municipality (LDM), approximately 15 km south-west of Virginia and 20 km north-east of Theunissen. The locality plan indicating the Joel Operation is presented in Figure 1-1. Joel is indicated by the blue boundary. The current status of the Joel Operation is described in Table 2-1.

Joel Operation is east of the provincial road between Welkom and Theunissen. Various internal tar and gravel roads exist which link all shafts and other working areas.

1.3 Applicant Details

The contact details of the responsible environmental personnel at Joel Operations are shown in Table 1-1 below.

© 2025 Kongiwe Environmental (Pty) Ltd

Table 1-1: Contact Details

Applicant	Harmony Gold Mining Company Limited
Registration No.	1950/038232/06
Primary Contact	Ipeleng Sebetlele
Alternative Contact	John van Wyk
Head Office Address	Randfontein Office Park Corner Main Reef Road and Ward Avenue Randfontein Gauteng 1759
Postal Address	PO Box 2 Randfontein Randfontein Gauteng 1759
Telephone	+ 27 57 733 7018
Fax	N/A
E-mail	ipeleng.sebetlele@harmony.co.za
Mine Address	Harmony Joel Mine, Theunissen, Free state
Central Co-ordinates of the Mine	28°15'25.77"S 26°49'21.55"E

1.4 Property Description

A description of the properties forming part of the Joel Operation's Mining Right area is presented in Table 1-2 below.

Table 1-2: Property Description

Operations	Farm Name	Farm ID	Farm Portion	Title Deeds	Landowner	Farm owner
Joel	Leeuwbult 580	RD	RE	T33509/2003	Freegold Harmony Pty Ltd	Freegold Harmony Pty Ltd
Joel	Leeuwfontein 256	RD	RE	T33509/2003	Freegold Harmony Pty Ltd	Freegold Harmony Pty Ltd

© 2025 Kongiwe Environmental (Pty) Ltd

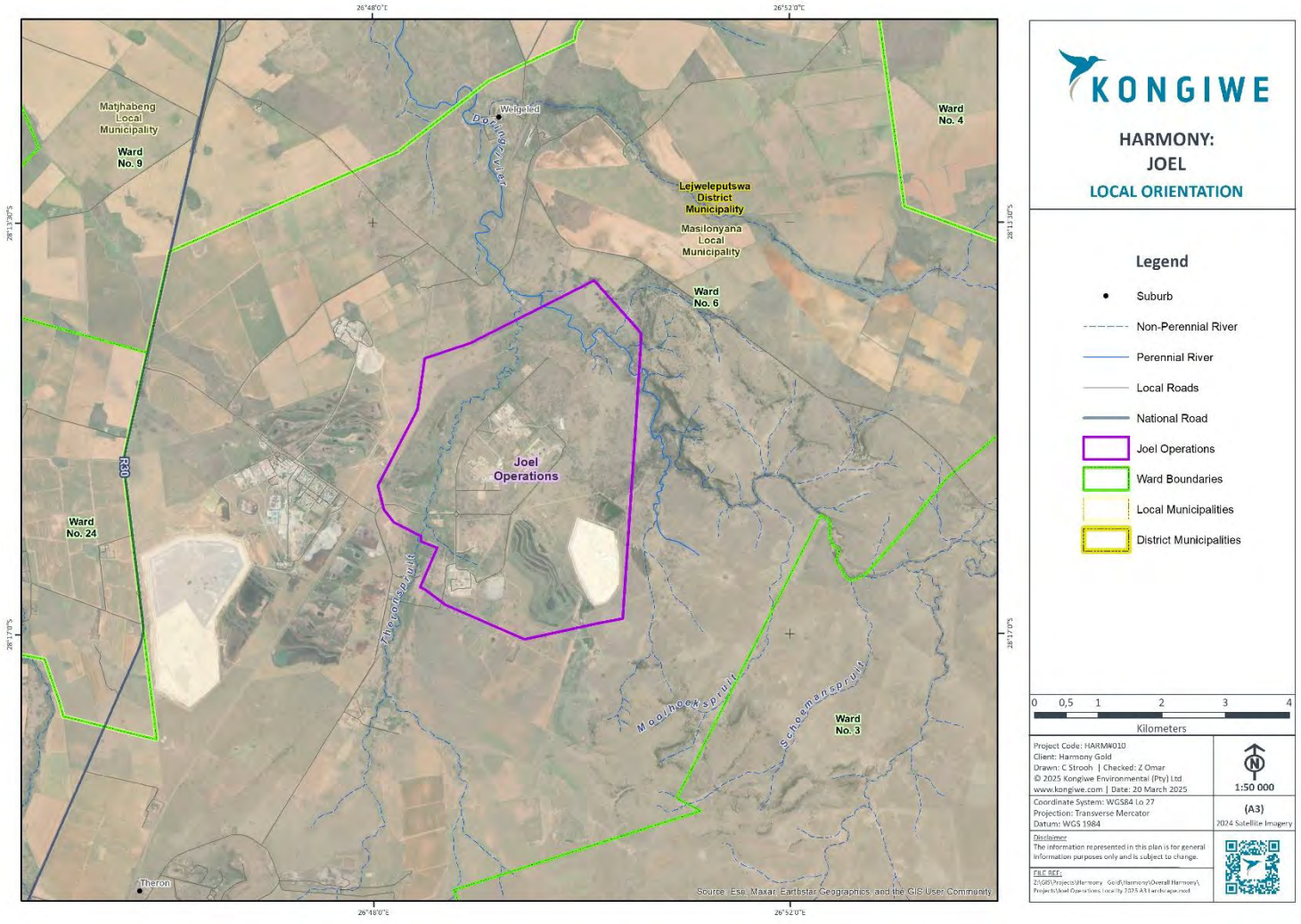


Figure 1-1: Joel Operation Locality Map

© 2025 Kongiwe Environmental (Pty) Ltd

1.5 Purpose of the IWWMP

From a legal perspective, this IWWMP fulfils the requirement of an Integrated Water Use Licence Application (IWULA), and provides a plan for managing the Joel Operation's Section 21 (a), (f), (g), (j), (c) and (i) water uses.

From a best management practice perspective, an IWWMP provides a mine with a consolidated approach for implementation of the Best Practice Guidelines (BPGs) (DWAF, 2006, 2008) to achieve integrated mine water management while simultaneously protecting the surrounding water resource.

This IWWMP is an outline of a comprehensive plan for the complete water and water-containing waste management cycle at the Joel Operation over the lifetime of the operations. It can be considered a living document, that will continue to be revised and updated annually throughout the life of the operations to accommodate additional information and improved technology. The updates are necessary to ensure that water and waste management is continually optimised and adapted to the changing needs of the water management area thereby reducing the risks of the operation to the environment and humans.

This IWWMP follows the content list as stipulated in Regulations Regarding the Procedural Requirements for Water Use Licence Applications and Appeals, GN R267, Government Gazette 40713, 24 March 2017. Information on the Operations has been sourced from the previous IWWMP (SRK, August 2020), and the relevant and most current specialist documents as provided in the reference list at the end of this report.

2. Project Conceptualisation

This section provides a description of the Operation's activities, processes and products. It also provides the background information of the organisational structure of the water user, i.e. Harmony.

2.1 Description of Activity

The Joel Operation occupies a portion of the Free State goldfield which is located in the south-western part of the Witwatersrand Basin. The Basal Reef is one of numerous gold-bearing conglomerates which are intercalated with quartzites and shales in the Central Rand Group of the Witwatersrand Supergroup.

The Witwatersrand sediments, which are approximately 2,7 billion years old , have been tilted and faulted, creating a complex geological structure which is generally regarded as a hindrance to mining. The Joel Operation exploits three auriferous conglomerating horizons, i.e. 'A' Reef, Leader Reef and Basal Reef of the Central Rand Group.

Over most of the Joel area, the Witwatersrand rocks are overlain by Ventersdorp lavas and sediments, which in turn, are overlain by younger Karoo rocks. The underground workings at the Joel Operation are approximately 1 492 m below surface, and the Beatrix Reef is the principal reef mined. The VS5 Reef is the furthest boundary of the mine. The standard open stooping layout for the extraction of narrow, generally flat dipping gold reefs method is undertaken at the Joel Operation.

Joel 1 Shaft is a material shaft and hoists all ore to the surface from the underground workings. Joel 3 Shaft is a man and material decline shaft. Ore from the Joel Operation is processed at the Harmony One Plant.

Current infrastructure at Joel includes the following:

- General Infrastructure - Workshops, Stores and administrative buildings.
- WRDs.
- Shafts.
- Processing Plant.
- Dams.

© 2025 Kongiwe Environmental (Pty) Ltd

- Sewage Treatment Plant.
- TSF.
- Hostels.
- Roads.

2.2 Extent of Activity

The mining lease area extends across approximately 2 161 ha on the properties indicated in Table 1-2. The boundary areas are presented in Figure 1-1 and the Master Plan included in the appendices of this report.

2.3 Key Activity Related Processes and Products

Mining at the Joel Operation includes underground workings approximately 1 492 m below ground level, which mainly concentrate on the Beatrix Reef and VS5 Reef. Ore from Joel mine is hoisted to the surface at Joel 1 Shaft and is then transported to Harmony One Plant via truck. The ore is milled at the Plant and the mills are operated in a closed circuit with cyclones. Overflow from the cyclones is fed back to the mill for regrinding, and low grade WRD material is also processed if it is economically viable. Waste rock from development of the shafts is disposed of at the shafts' waste rock dumps.

The gold recovery process involves an acid wash, followed by the elution on carbon. The electrolyte solution is pumped through an electro wining circuit, where gold is deposited onto cathodes.

Underground mining was initiated in 1978, and the Joel Operation has approximately four years left of its Life of Mine (LoM). The Joel South Shaft (also known as the Joel 3 Shaft or Taung South Shaft) is used as a man and material decline shaft. The Joel Plant is currently non-operational and is under care and maintenance.

A summary of the operations and the water and waste management systems associated with the Joel Operation are presented in Table 2-1, and additional details are provided in the remainder of this section. The mine layout is presented in Figure 2-1 and the Master Plan in Appendice A.

2.4 Activity Life Description

Mining at the Joel Operations was initiated during 1978. The approximate life of the current operations is approximately 4 years, until at least 2029.

2.5 Activity Infrastructure Description

A summary of the current operations and water and waste management systems at the Joel Operation is presented in Table 2-1 and illustrated by Figure 2-1. The location of the various operations is presented in the Master Plan in the appendices.

© 2025 Kongiwe Environmental (Pty) Ltd

Table 2-1: Description of the Joel Operations Mining Activities

Aspect	Method / System
Mining	
Underground Mining	• Mining is undertaken at Joel 3 Shaft and hoisting is undertaken at Joel 1 North. • The total run of mine volume is provided by underground mining. • The Beatrix Reef and VS5 Reef are mined. • Mining depths are currently approximately 1 492 m below ground level.
Beneficiation	
Metallurgical Plant	• Mined ore is processed at the Harmony One Plant. • Joel Plant is currently not operational (under care & maintenance). • Gold is smelted at Rand Refinery. • Tailings from the Joel Plant were disposed at the Joel Tailings Storage Facility (TSF) Complex. However, the TSF is now dormant.
Water and waste management systems	
Water Supply	• The Joel Operation receives water supply from Vaal Central Water, and this water is used for domestic purposes and supplements mining and metallurgical purposes.
Dirty (waste) Water Containment and Release	• Dirty water (process water) is contained in a return water dam. • Dirty water runoff from the shafts and processing areas is contained in the return water dam. • Water from the dirty water containment facilities including the return water dam is reused in mining processes and/or evaporated.
Clean Water Diversions	• Clean water diversions are in place at the shafts, processing areas and waste storage facilities (i.e. TSF and WRD) to direct runoff from the surrounding catchment, away from the dirty areas.
Waste Rock	• Waste rock from the shafts is sent to the Joel North WRD. No waste rock is currently being processed for the Joel Operations.
Tailings	• No tailings are currently being transported – the plant is not operational.
Domestic and Industrial Waste	Standard operating procedures have been developed for waste management at the Joel Operation. • Domestic waste generated at the Joel Operation is taken off-site to a registered landfill site. • Industrial waste is handled at the shaft and processing areas in designated waste areas. Scrap metal, wood and plastic are recycled through the Salvage Yard. • Hazardous waste is handled by the appointed contractor, currently Mico Trading, and is transported off-site to a registered hazardous waste facility.
Sewage	• Sewage effluent at the Joel Operation is handled at the Joel Sewage Treatment Plant. • Treated sewage effluent is discharged into the Theronspruit.
Surface Infrastructure	
General	The support infrastructure associated with the Joel Operation includes:

© 2025 Kongiwe Environmental (Pty) Ltd

Aspect	Method / System
Infrastructure	• Administration offices; • Change houses; • Engineering workshops; • Salvage yard; and • Hostels.

© 2025 Kongiwe Environmental (Pty) Ltd

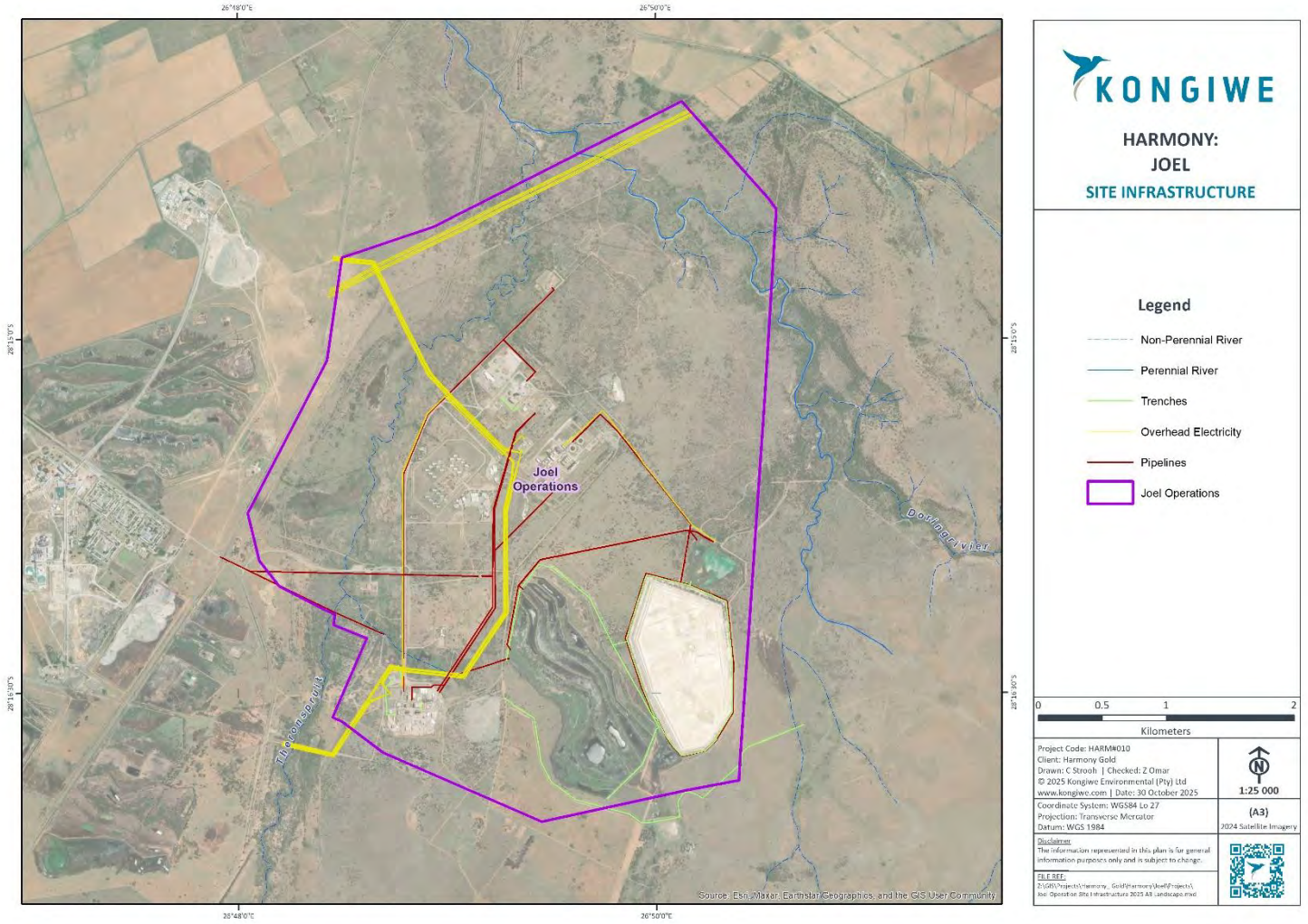


Figure 2-1: Joel Operation Site Infrastructure Map

© 2025 Kongiwe Environmental (Pty) Ltd

2.6 Key Water Uses and Waste Streams

2.6.1 Water Supply

2.6.1.1 Potable Water

Potable water is supplied by Vaal Central Water and is used at the Joel Operation for domestic purposes and supplements mining and metallurgical purposes. The plant is currently in care and maintenance. Monthly and annual potable water use from March 2024 to February 2025 are presented in Table 2-2 for Joel 1 Shaft. Monthly and annual potable water use from March 2024 to February 2025 are presented in Table 2-3 for Joel 3 Shaft.

Table 2-2: Potable Water Consumption for 2024 and 2025 (m^3) for Joel 1 Shaft

Year	Month	Joel Plant	Joel 1 Shaft
2024	March	0	980
	April	0	838
	May	0	882
	June	0	754
	July	0	761
	August	0	711
	September	0	6 230
	October	0	6 360
	November	0	7 580
	December	0	6 270
2025	January	0	13 130
	February	0	8 000
Total 2024 and 2025		**0**	**52 496**

Table 2-3 Potable Water Consumption for 2024 and 2025 (m3) for Joel 3 Shaft

Year	Month	Joel Plant	Joel 3 Shaft
2024	March	0	42 795
	April	0	38 666
	May	0	25 960
	June	0	26 420
	July	0	26 670
	August	0	35 208
	September	0	42 538
	October	0	58 592
	November	0	45 045
	December	0	32 342
2025	January	0	54 500
	February	0	39 897
Total 2024 and 2025		**0**	**468 633**

© 2025 Kongiwe Environmental (Pty) Ltd

2.6.1.2 Process Water

Process water supply at the Joel Operation is made up of recycled water, potable and raw water supply. The process water supply sources in order of priority include:

- Tailings return water.
- Stormwater runoff (refer to Section 2.6.3).
- Water removed from underground at Joel 3 Shaft.
- Make-up water (Vaal Central Water).

Process water is contained in the return water dams that were constructed for this purpose.

2.6.2 Sewage Effluent

All sewage from the Joel Operations is directed to the Joel Sewage Treatment Plant. The sewage treatment plant is operated and maintained by an appointed contractor. Excess treated sewage effluent is discharged into the Theronspruit.

2.6.3 Stormwater Management

Stormwater management infrastructure is designed to cater for both clean and dirty stormwater runoff. Clean water runoff is generated upstream of the potentially contaminating infrastructure, while dirty stormwater runoff is generated within or in the vicinity of the mine infrastructure.

Stormwater management measures and recommendations for the Joel Operation are presented in Section 5.4.

2.7 Organisational Structure of Activity

The persons who are responsible for the implementation of this IWWMP and future WUL are presented in Table 2-4.

Table 2-4: Persons Responsible for Implementation of the IWWMP and Future WUL Commitments

Harmony - Joel Operations	
Postal Address	P.O. Box 2 Randfontein 1760
Name	**Designation**
John van Wyk	Group Senior Environmental Manager
Ipeleng Sebetlele	Environmental Officer

2.8 Business and Corporate Policies Related to the Environment

Harmony aspires to leave a net positive legacy at all its operations. Excellence in environmental management performance is regarded as essential to Harmony's business success. In order to protect the environment, Harmony has committed to the following:

- Aim to prevent pollution, or otherwise minimise, mitigate and remediate harmful effects of operations on the environment throughout their lifecycle.
- Ensure that compliance with all applicable environmental laws, regulations and standards is the foundation on which Harmony's environmental performance is built.
- Promote active partnerships with government, community, labour and other relevant organisations for environmental protection and conservation at international, national, regional and local levels.

© 2025 Kongiwe Environmental (Pty) Ltd

- Develop, implement and maintain environmental management systems to identify and manage risks, to inform decision making and to drive continual improvement throughout the organisation.
- Set and achieve targets that promote efficient use of resources and reduce environmental exposure and report on progress to relevant internal and external stakeholders.
- Manage hazardous substances safely and responsibly.
- Contribute to biodiversity protection considering ecological values and land-use aspects in investment, operational and closure activities.
- Ensure transparent engagement on environmental issues with communities affected by the Harmony operations and consider their views and concerns in the company's decision making.
- Continue to invest in research and development, as innovation is regarded as core to improving long term environmental outcomes within the realms of economically and ecologically sustainable development.
- Close mines in a manner that promotes ecological and socio-economic sustainability.

3. Regulatory Water and Waste Management Framework

There are a number of legal and regulatory frameworks which regulate mine water management in South Africa. A summary of these are provided below with specific detail relating to the Nation Water Act (NWA) and National Environment Management: Waste Act, 2008 (Act No. 59 of 2008) (NEM:WA) provided in the remainder of this section.

Table 3-1: Water Management Legal and Regulatory Framework Requirements

Legislation
Constitution of the Republic of South Africa, 1996 Describes the Bill of Rights and is the cornerstone of democracy in South Africa, enshrining the rights of all people and affirming the democratic values of human dignity, equality and freedom. Section 24 is directly relevant to environmental law. The Bill of Rights states that everyone has the right to an environment that is not harmful to their health or well-being.
National Water Act (Act No. 36 of 1998) (NWA) Section 19 of the NWA sets out the principles for "an owner of land, a person in control of land or a person who occupies or uses land" to: • Cease, modify or control any act or process causing pollution. • Comply with any prescribed waste standard or management practice. • Contain or prevent the movement of pollutants. • Eliminate any source of pollution. • Remedy the effects of the pollution. • Remedy the effects of any disturbance to the bed and banks of a watercourse. It also describes the actions that can be taken by the catchment management agency to enforce the requirements of the NWA.

© 2025 Kongiwe Environmental (Pty) Ltd

Legislation
The NWA Amendment Act (Act No. 27 of 2014) This Act makes provision for integration and alignment of the WULA process with applications undertaken in terms of the NEMA and Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002) (MPRDA).
NWA Regulations: **Regulation 704 (GN R704, Gazette No. 20119, 1999)** This Regulation enforces the separation of clean and dirty water systems and includes restrictions of mining related activities within the 1:100 year floodline or 100 m from a watercourse, and within the 1:50 year floodline. **Regulations regarding the procedural arrangements for water use licence applications and appeals (GN R267, Gazette No. 40713, 24 March 2017)** The final decision on the WULA is required within 90 calendar days from submission of the application. **The General Authorisation for Section 21(c) and (i) water uses (GN509, Gazette No. 40229, 26 August 2016)** Defines a regulated area of a watercourse as: The outer edge of the 1 in 100 year floodline and/or delineated riparian habitat, whichever is the greatest distance, measured from the middle of the watercourse of a river, spring, natural channel, lake or dam; in the absence of a determined 1 in 100 year floodline or riparian area the area within 100 m from the edge of a watercourse where the edge of the watercourse is the first identifiable annual bank fill flood bench; or a 500 m radius from the delineated boundary (extent) of any wetland or pan.
Water Services Act (Act No. 108 of 1997) (WSA) Provides for the regulation of water boards and the setting of national water quality standards.
National Environment Management Act (Act No. 107 of 1998) (NEMA) Sections 28 (1) and (3) of NEMA set out the duty of care principle, which is applicable to all types of pollution and must be taken into account in considering any aspects of potential environmental degradation. Every person who causes, has caused or may cause significant pollution or degradation of the environment must take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring, or, in so far as such harm to the environment is authorised by law or cannot reasonably be avoided or stopped, to minimise and rectify such pollution or degradation of the environment.
Environmental Impacts Assessment Regulations, 2014 as amended These regulations were developed for the preparation, evaluation, submission, processing and consideration of, and decision on, applications for environmental authorisations.
National Environment Management: Waste Act (Act No. 59 of 2008) (NEM:WA) Follows the principle that waste generation be avoided, or if it cannot be avoided, that it is reduced, reused, recycled or recovered, and as a last resort treated and/or safely disposed of. The objects of this Act are to protect health, well-being and the environment by providing reasonable measures for- • minimising the consumption of natural resources. • avoiding and minimising the generation of waste. • reducing, re-using, recycling and recovering waste.

© 2025 Kongiwe Environmental (Pty) Ltd

Legislation
• treating and safely disposing of waste as a last resort. • preventing pollution and ecological degradation. • securing ecologically sustainable development while promoting justifiable economic and social development. • promoting and ensuring the effective delivery of waste services. • remediating land where contamination presents, or may present, a significant risk of harm to health or the environment. • achieving integrated waste management reporting and planning. • to ensure that people are aware of the impact of waste on their health, well-being and the environment; • to provide for compliance with the measures set out in paragraph (a). • generally, to give effect to section 24 of the Constitution in order to secure an environment that is not harmful to health and well-being. The National Environmental Management Laws Amendment, 2022, once fully implemented, will reverse the inclusion of mine residues under NEM:WA and return these to NEMA.
Waste Classification and Management Regulations The Waste Classification and Management Regulations require that all waste generators must ensure that the waste their generated waste is classified in accordance with SANS 10234 within 180 days of generation, and if the waste is to be disposed of to landfill, that the waste is assessed in accordance with the Norms and Standards for Assessment of Waste for Landfill Disposal.
Regulations Regarding the Planning and Management of Residue Stockpiles and Residue Deposits 2015 – refer to Section 3.6 for additional details The regulations specify the requirements relating to residue stockpiles and residue deposits as follows: • Assessment of impacts and analysis of risks. • Characterisation. • Classification. • Site selection. • Design. • Impact management. • Monitoring and reporting. • Dust management and control. • Decommissioning, closure and post closure management.
The National Environmental Management: Biodiversity Act (Act No. 10 of 2004) (NEM:BA) The Act seeks amongst other things, to manage and conserve biological diversity, to protect certain species and ecosystems, to ensure the sustainable use of biological resources and to promote the fair and equitable sharing of benefits arising from bioprospecting involving those resources. The NEM:BA includes a Regulation related to the management of threatened and protected species. A similar Regulation is applied to Threatened Ecosystems. NEM:BA has a set of norms and standards for the development of management plans for both species (e.g. Threatened or Migratory Species) and ecosystems (Endangered or Critically Endangered).
Mineral and Petroleum Resources Development Act (Act No. 28 of 2002) (MPRDA) The MPRDA makes provision for equitable access to and sustainable development of South Africa's mineral resources. The MPRDA requires that the environmental management principles set out in NEMA shall apply

© 2025 Kongiwe Environmental (Pty) Ltd

Legislation
to all mining operations and serves as a guideline for the interpretation, administration and implementation of the environmental requirements of NEMA.

In addition to the above, the DWS has developed the National Water Resource Strategy (NWRS) to give effect to Section 5 of the NWA. The second edition of the NWRS (NWRS2, DWA 2013) is the primary mechanism to manage water across all sectors towards achieving national government's development objectives. The water sector vision for the NWRS2 is "Sustainable, equitable and secure water for a better life and environment for all" and is aligned with the vision of South Africa 2030. Towards achieving this vision, the overall goal is: "Water is efficiently and effectively managed for equitable and sustainable growth and development". The NWRS2 strives to achieve three main objectives (DWA, 2013):

- Water supports development and the elimination of poverty and inequality.
- Water contributes to the economy and job creation.
- Water is protected, used, developed, conserved, managed and controlled sustainably and equitably.

The core strategies of the NWRS2 (DWA, 2013) include the following:

- Implementation of Equity Policy.
- Putting water at the centre of integrated development planning and decision-making.
- Ensuring water for equitable growth and development.
- Contributing to a just and equitable South Africa.
- Prioritising and ensuring the implementation of water conservation and demand management.
- Optimising and stretching of our available water resources (groundwater, water reuse, desalination (including seawater), water systems optimization and rainwater harvesting).
- Committing to the protection of our water resources and ecosystems.
- Achieving effective and smarter water governance.
- Embedding sustainable business principles and practices in water resources and systems management.
- Implementing a water sector investment framework for infrastructure, human resource capacity and institutions.
- Engaging the private and water use sectors.

Strategic actions have been developed per sector for the key priority areas. Measures to give effect to the strategies and priority areas at the Joel Operation are discussed in Section 6.2 of this IWWMP.

3.1 Summary of all Water Uses

The current Section 21 (a), (b), (f), (g), (j), (c) and (i) water uses requiring authorisation for the Joel Operation are presented in Table 1-2. All water uses in Table 1-2 are presented in the Master Plan in Appendice A.

3.2 Existing Lawful Water Uses

Existing lawful water use (ELU) in terms of Section 32 of the NWA applies to water uses that physically took place in the two years preceding the promulgation of the NWA (from 1 October 1996 to 30 September 1998 for groundwater and 1 October 1997 to 30 September 1999 for surface water) and which had been lawful in terms of previous legislation. The water uses that may constitute existing lawful water uses are presented in Table 3-2.

Water permits/exemption permits for various water uses associated with the Joel Operation were issued by DWS (then the Department of Water Affairs and Forestry (DWAF)), under the old Water Act, Act 54 of 1956. The water uses for the following permits are still in operation and thus included in this WULA:

- 3M.

© 2025 Kongiwe Environmental (Pty) Ltd

- 1459B.
- 1339N.
- QC404.00.XR01.
- 1460B.
- B33/2/340/116/P35.
- B33/2/340/21/P8.

Table 3-2: List of Permits Authorised by DWAF for the Joel Operation

Permit Number	Date of Issuance	Issued To	Permit Description
3M	27 May 1991	HJ Joel Gold Mining Company	Discharge of 20 000 m³/day of water found underground via pipeline to mines in Welkom
1459B	27 May 1991	HJ Joel Gold Mining Company	Discharge (disposal) of 996 812 m³/a into TSF and evaporation pond system
1339N	15 March 1991	HJ Joel Gold Mining Company	Use of 1 370 575 m³/a from various sources
QC404.00.XRO1	18 August 1996	Johannesburg Consolidated Investment Company Ltd	Joel Sewage Treatment Works
1460B	15 March 1991	HJ Joel Gold Mining Company	Disposal (discharge) of 187 610 m³/a into Theronspruit.
			Use of 514 m³ per day for irrigation of gardens
B33/2/340/116/P35	14 March 1992	HJ Joel Gold Mining Company	HJ Joel Class 2 Waste Disposal Site
B33/2/340/21/P8	16 March 1992	Welkom City Council	Freegold South Class 2 Waste Disposal Site

© 2025 Kongiwe Environmental (Pty) Ltd

3.3 Relevant Exemptions

Regulation GN704 (Government Gazette 20118, 4 June 1999), under the NWA, stipulates conditions for managing water on a mine. The Regulation GN704 exemptions required are presented in Table 3-3.

Table 3-3: Regulation GN704 Exemptions

Activity	Applicable GN 704 regulations	Motivation / Reason for Exemption
The operation and rehabilitation of the Joel Stormwater Dam within a 500 m wetland buffer.	**Regulation 6: Capacity requirements of clean and dirty water systems** 6(c): Capacity requirements of clean and dirty water systems 6(d): Design, construct, maintain and operate any dirty water system at the mine or activity so that it is not likely to spill into any clean water system more than once in 50 years. **Regulation 7: Protection of water resources** 7(a): prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act.	The facility is present on Landsat imagery that pre-dates June 1999 (when GN R704 was enacted), and therefore it is likely that this dam was already being used to contain dirty water.
The operation and rehabilitation of the Joel 1 North (Taung North) Shaft Waste Rock Dump within a 500 m wetland buffer.	**Regulation 6: Capacity requirements of clean and dirty water systems** 6(c): Capacity requirements of clean and dirty water systems **Regulation 7: Protection of water resources** 7(a): prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act.	The facilities are present on aerial imagery that pre-dates GN R704.
The operation and rehabilitation of the Joel Evaporation Dam within a 500 m wetland buffer and 100 m stream buffer.	**Regulation 6: Capacity requirements of clean and dirty water systems** 6(c): Capacity requirements of clean and dirty water systems **Regulation 7: Protection of water resources** 7(a): prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act.	The facility is present on aerial imagery that pre-dates GN R704.
The reclamation and rehabilitation of the Joel TSF Complex, and operation and rehabilitation of the associated pipelines within a 500 m wetland buffer.	**Regulation 6: Capacity requirements of clean and dirty water systems** 6(c): Capacity requirements of clean and dirty water systems **Regulation 7: Protection of water resources** 7(a): prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act. **Regulation 4: Restrictions on locality** 4(a): locate or place any residue deposit, dam, reservoir, together with any associated structure or any other facility within the 1:100-year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, borehole or well, excluding boreholes or wells drilled specifically to monitor the pollution of groundwater, or on water-logged ground, or on ground likely to become water-logged, undermined, unstable or cracked	The facilities are present on aerial imagery that pre-dates GN R704.
The operation and rehabilitation of the Joel North and South Waste Rock Dumps	**Regulation 6: Capacity requirements of clean and dirty water systems** 6(c): Capacity requirements of clean and dirty water systems **Regulation 7: Protection of water resources** 7(a): prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act.	The facilities are present on aerial imagery that pre-dates GN R704.
Shafts and mine area	**Regulation 5:** May not use any residue or substance which causes or is likely to cause pollution of water resource for the construction of any dam or other impoundment or any embankment, road or railway or for any other purpose which is likely to cause pollution of a water resource.	An exemption is required to use reclaimed waste rock from the operation's waste rock dumps to backfill decommissioned shafts for safety purposes, and as aggregate material for construction and other infrastructure. An exemption is required to use tailings material for the purposes of rehabilitation, minimising the unauthorized increase of the underground workings and for safety purposes.

© 2025 Kongiwe Environmental (Pty) Ltd

3.4 Generally Authorised Water Uses

There are no Geneal Autorisations (GAs) applicable to the Joel Operation. Harmony is undertaking a a full IWULA for water use activities associated with the operation.

3.5 Previous Water Use Applications

A WULA was submitted to the former Department of Water Affairs (DWA), now the Department of Water and Sanitation (DWS), in 2009, however, due to various reasons, the WULA was not processed.

In 2020 Harmony – Joel Operation applied for a Water Use Licence (WUL) to authorise the identified Section 21 water uses associated with the operations. This excluded the 21 (c) and (i) activities applied for in this application.

Therefore, the IWULAs for the Section 21 (c) and (i) water uses were undertaken between 2022 and 2023. In 2024 the DWS and Harmony came to an agreement that water uses for the 2020 applications as well as the 2022-2023 applications must be combined and submitted as a single application for each respective operation.

3.6 New Water Uses to be Licensed

All water uses at the Joel Operation are considered as new uses and are presented in Table 3-4 and Figure 3-1.

© 2025 Kongiwe Environmental (Pty) Ltd

Table 3-4: Section 21 Water Uses Requiring Authorisation for the Joel Operations

ID	Source / Infrastructure	Purpose / Description	Properties	Coordinates
J_A1	Joel 3 South Shaft	Reuse of water removed from underground for the continuation of mining	Leeuwfontein 256 RD, RE	28° 16' 34.96" S 26° 48' 48.45" E
J_B1	Joel Stormwater Dam	Process water dam containing stormwater runoff	Leeuwfontein 256 RD, RE	28° 16' 22.18" S 26° 48' 54.03" E
J_F1	Joel Sewage Plant	Discharge of treated sewage effluent into the Theronspruit	Leeuwbult 580 RD, RE	28° 14' 45.21" S 26° 49' 23.03" E
J_G1	Joel Evaporation Dams	Excess water from the shafts and return water dam (emergency use only)	Leeuwfontein 256 RD, RE	28° 16' 29.35" S 26° 49' 37.66" E
J_G2	Joel 3 South Shaft TK1 Water Tank	Contains water abstracted from underground	Leeuwbult 580 RD, RE	28° 16' 34.64" S 26° 48' 43.64" E
J_G3	Joel Sewage Plant	Sewage treatment plant	Leeuwbult 580 RD, RE	28° 14' 44.46" S 26° 49' 28.79" E
J_G4	Joel 3 South (Taung South) Shaft Waste Rock Dump	Waste rock dump (dormant)	Leeuwfontein 256 RD, RE	28° 16' 37.12" S 26° 49' 09.55" E
J_G5	Joel Slime Dam Complex	Tailings storage facility (dormant)	Leeuwfontein 256 RD, RE	28° 16' 22.28" S 26° 50' 08.07" E

© 2025 Kongiwe Environmental (Pty) Ltd

ID	Source / Infrastructure	Purpose / Description	Properties	Coordinates
J_G6	Joel Return Water Dam	Return Water Dam	Leeuwfontein 256 RD, RE	28° 15' 57.78" S 26° 50' 14.86" E
J_G7	Settler Dams	Mud storage area	Leeuwfontein 256 RD, RE	28° 16' 25.98" S 26° 48' 44.82" E
J_J1	Joel 3 South Shaft	Reuse of water removed from underground for efficient continuation of underground workings	Leeuwfontein 256 RD, RE	28° 16' 34.96" S 26° 48' 48.45" E
1	Joel 3 South (Taung South) Shaft and associated pipelines	The operation and rehabilitation of the Joel 3 South (Taung South) Shaft, associated pipelines, and shaft related infrastructure within a 500 m wetland buffer.	Portion 0 (RE) of Leeuwfontein 256 RD	Start: 28° 16' 23.84" S 26° 49' 54.38" E End: 28° 16' 36.11" S 26° 50' 21.23" E
2	Joel 1 North (Taung North) Shaft & Metallurgical Plant and associated pipelines	The operation and rehabilitation of Joel 1 North (Taung North) Shaft and Metallurgical Plant, its associated pipelines, and related infrastructure within a 500 m wetland buffer.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 16' 23.84" S 26° 49' 54.38" E End: 28° 16' 36.11" S 26° 50' 21.23" E

© 2025 Kongiwe Environmental (Pty) Ltd

ID	Source / Infrastructure	Purpose / Description	Properties	Coordinates
3	Joel 1 North (Taung North) Shaft Waste Rock Dump (Dormant)	The rehabilitation of the Joel 1 North (Taung North) Shaft Waste Rock Dump within a 500 m wetland buffer.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 15' 12.69" S 26° 49' 46.51" E
				End: 28° 15' 12.69" S 26° 49' 46.51" E
4	Joel Sewage Plant	The operation and rehabilitation of the Joel Sewage Plant within a 500 m wetland buffer and its associated tributaries.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 16' 23.84" S 26° 49' 54.38" E
				End: 28° 16' 36.11" S 26° 50' 21.23" E
5	Joel Hostel Area	The operation and rehabilitation of pipelines transporting potable water within a 500 m wetland buffer and its associated tributaries.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 15' 33.59" S 26° 48' 50.33" E
				End: 28° 15' 33.85" S 26° 49' 8.65" E

© 2025 Kongiwe Environmental (Pty) Ltd

ID	Source / Infrastructure	Purpose / Description	Properties	Coordinates
6	Potable Water Pipeline Buffer Crossing 1	The rehabilitation of pipelines transporting potable water within a 500 m wetland buffer and its associated tributaries.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 15' 58.965" S 26° 48' 3.338" E
				End: 28° 15' 59.478" S 26° 48' 24.024" E
7	Potable Water Pipeline Wetland Crossing 1	The rehabilitation of pipelines transporting potable water within a wetland and 1:100 year flood line.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 15' 59.478" S 26° 48' 24.024" E
				End: 28° 15' 59.906" S 26° 48' 47.785" E
8	Potable Water Pipeline Buffer Crossing 2	The rehabilitation of pipelines transporting potable water within a 500 m wetland buffer and its associated tributaries.	10 Start: Portion 0 (RE) of Leeuwbult 580 RD 10 End: Portion 0 (RE) of Leeuwfontein 256 RD	Start: 28° 15' 59.906" S 26° 48' 47.785" E
				End: 28° 16' 0.242" S 26° 49' 6.211" E

© 2025 Kongiwe Environmental (Pty) Ltd

ID	Source / Infrastructure	Purpose / Description	Properties	Coordinates
9	Return Water Pipeline Wetland Crossing 1	The rehabilitation of pipelines transporting return water within a wetland and its associated tributaries.	Portion 0 (RE) of Leeuwbult 580 RD	Start: 28° 14' 47.115" S 26° 49' 30.303" E
				End: 28° 14' 58.936" S 26° 49' 17.762" E
10	Return Water Pipeline Buffer Crossing 1	The rehabilitation of pipelines transporting return water within a 500 m wetland buffer and its associated tributaries.	12 Start: Portion 0 (RE) of Leeuwbult 580 RD 12 End: Portion 0 (RE) of Leeuwfontein 256 RD	Start: 28° 14' 58.936" S 26° 49' 17.762" E
				End: 28° 16' 29.453" S 26° 48' 47.480" E

© 2025 Kongiwe Environmental (Pty) Ltd

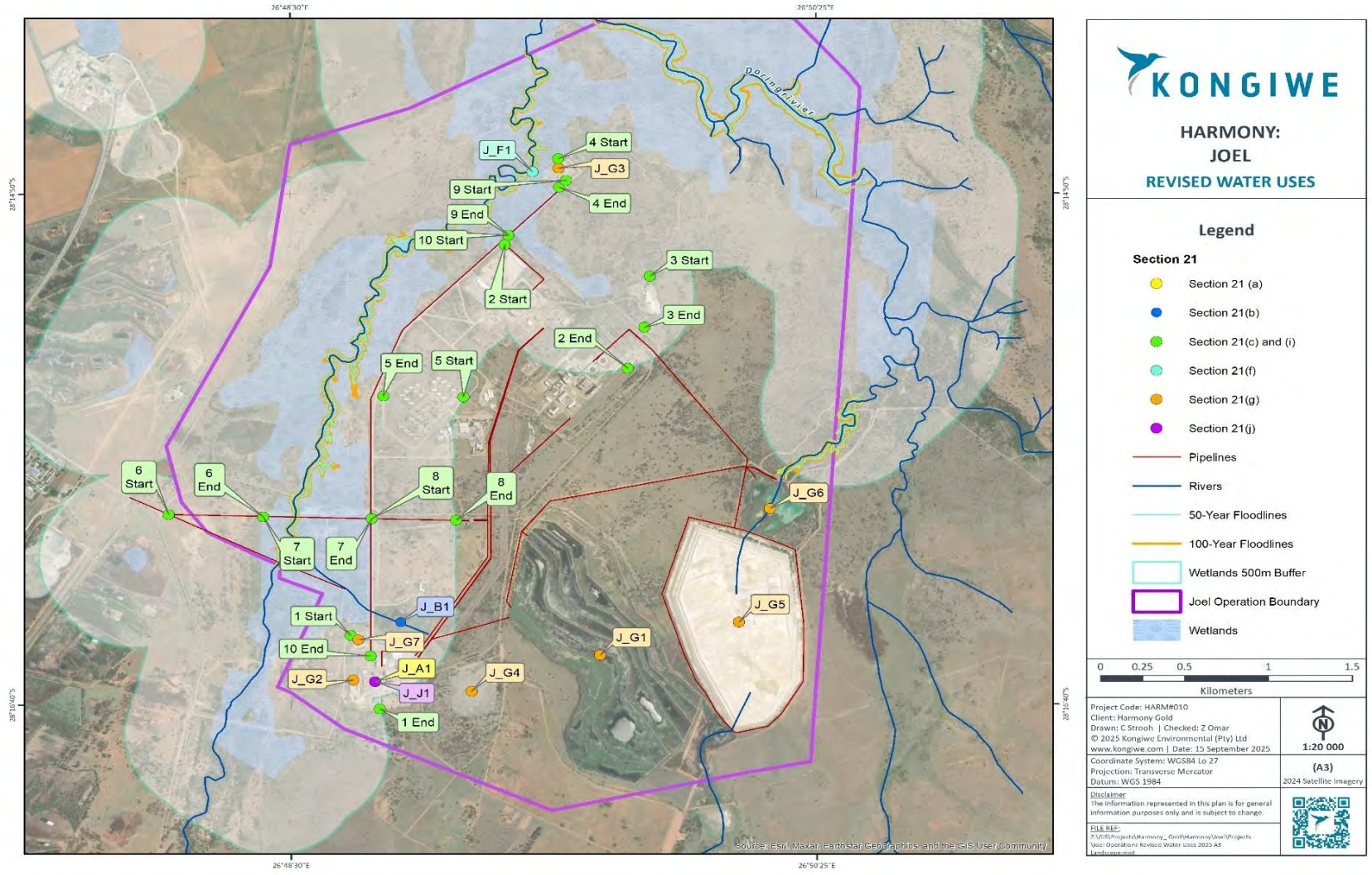


Figure 3-1: Joel Water Use Map

© 2025 Kongiwe Environmental (Pty) Ltd

3.7 Waste Management Activities (NEM:WA)

Waste is regulated under the NEM:WA as well as the National Environmental Management: Waste Amendment Act, 2014 (Act No. 26 of 2014) (NEM:WAA), with the exception of certain listed exclusions.

NEM:WA follows the principle that waste generation is to be avoided, or if it cannot be avoided, that it be reduced, reused, recycled or recovered, and as a last resort treated and/or safely disposed of (described further in Section 5.6). Although the Minister of Mineral Resources is the licensing authority for residue stockpiles and residue deposits, their management must be in accordance with the NEM:WA Regulations as prescribed by the Minister of Forestry and Fisheries and Environment (DFFE) (previously known as the Department of Environmental Affairs). The list of Waste Management Activities that may require licensing in terms of NEM:WA has been revised as follows:

- On 29 November 2013 (Government Notice (GN) 921, Government Gazette No 37083) to exclude treatment of effluent, wastewater or sewage.
- On 2 May 2014 (GN332, Government Gazette No. 37604) to exclude remediation of contaminated land, now covered under Norms and Standards.
- On 24 July 2015 (Government Gazette GG 39020, GN: R633) to include residue stockpiles and residue deposits.
- On 24 June 2022 (Government Gazette No 46602, GN: R 684) to provide for the exclusion of residue stockpiles and residue deposits from the provisions of the Act.
- As well as several other administrative amendments.

Regulations that have relevance to the planning and management of mine residues and stockpiles and general waste management include the following:

- Government Gazette No. 39020, GN: R632, 24 July 2015: deals with characterisation and classification of the residue; investigation and the selection of sites; design; assessment/prediction of impacts; analysis of risk relating to the management of residue stockpiles and deposits; duties of permit holders; monitoring and reporting; dust management; and decommissioning, closure and post-closure management.
- Government Gazette 41920, GN: R990, 21 Sep 2018: Amendment to GNR632 to allow for pollution control measures required for residue stockpiles and deposits to be determined on a case-by-case basis, based on a risk analysis conducted by a competent person.
- National Norms and Standards in Government Gazette No. 36784, 23 August 2013 for Waste Classification and Management (GN R364), Assessment of Waste for Landfill Disposal (GN R365) and Disposal of Waste to Landfill (GN R636).
- National Norms and Standards in Government Gazette No 37083, 29 November 2013 for Storage of Waste (GN 926). GN926 require that general and hazardous waste storage facilities that can handle in excess of 100 m^3 and 80 m^3 of waste continuously, respectively should be registered. Biannual internal audits and biennial external audits of the registered facilities against the requirements of GN926 are required.
- National Norms and Standards in Government Gazette No. 37603, 2 May 2014 for Remediation of Contaminated Land and Soil Quality in the Republic of South Africa (GN331). A Site Assessment Report may be required for the land where the soil contamination is assessed in regard to the Norms and Standards.
- Regulations that have relevance to the planning and management of mine residues and stockpiles and general waste management include the following:
    - Government Gazette No. 39020, GN: R632, 24 July 2015: deals with characterisation and classification of the residue; investigation and the selection of sites; design;

© 2025 Kongiwe Environmental (Pty) Ltd

assessment/prediction of impacts; analysis of risk relating to the management of residue stockpiles and deposits; duties of permit holders; monitoring and reporting; dust management; and decommissioning, closure and post-closure management – when the National Environmental Management Laws Amendment Bill is promulgated these will be deemed to have been promulgated in terms of NEMA.

- Government Gazette 41920, GN: R990, 21 Sep 2018: Amendment to GNR632 to allow for pollution control measures required for residue stockpiles and deposits to be determined on a case by case basis, based on a risk analysis conducted by a competent person.
- National Norms and Standards in Government Gazette No. 36784, 23 August 2013 for Waste Classification and Management (GN R364), Assessment of Waste for Landfill Disposal (GN R365) and Disposal of Waste to Landfill (GN R636). The Norms and Standards for waste required wastes to be evaluated within 18 months to three years of the date at which the legislation was promulgated i.e. by August 2016.
- National Norms and Standards in Government Gazette No 37083, 29 November 2013 for Storage of Waste (GN 926). GN926 require that general and hazardous waste storage facilities that can handle in excess of 100 m^3 and 80 m^3 of waste continuously, respectively should be registered. Biannual internal audits and biennial external audits of the registered facilities against the requirements of GN926 are required.
- National Norms and Standards in Government Gazette No. 37603, 2 May 2014 for Remediation of Contaminated Land and Soil Quality in the Republic of South Africa (GN331). A Site Assessment Report may be required for the land where the soil contamination is assessed in regard to the Norms and Standards.

3.8 Other Authorisations (EMPrs, EIAs, RODs, Regulations)

The Environmental Management Programmes (EMPrs) associated with the Joel Operation are as follows:

- Joel Mine EMPr (FS 30/5/1/2/3/2/1 (13) EM; DMR Ref: FS 30/5/1/2/2/13 MR), dated February 2009, approved on 16 April 2010.
- Joel Mine EMPr (FS 30/5/1/2/3/2/1 (13) EM; DMR Ref: FS 30/5/1/2/2/13 MR), dated March 2019.

© 2025 Kongiwe Environmental (Pty) Ltd

4. Present Environmental Situation

4.1 Climate

The climate of the region has typically hot summers and cold dry winters, with the highest temperatures occurring in December/January and the lowest in June/July. Temperatures range from 34°C to -3°C. The area is predominantly dominated by winds directed from the northwest and are strongest in the afternoons.

4.1.1 Regional Climate Rainfall

Rainfall data from 1980 to 2016 was sourced from the National Aeronautics and Space Administration's (NASA) Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) dataset. The possibility of wet days in Welkom varies notably throughout the year. The mean monthly rainfall is indicated in Figure 4-1. Rainfall is highest in the months of October to April, and lowest over May to September. February has the most rainy days, while July has the fewest rainy days.

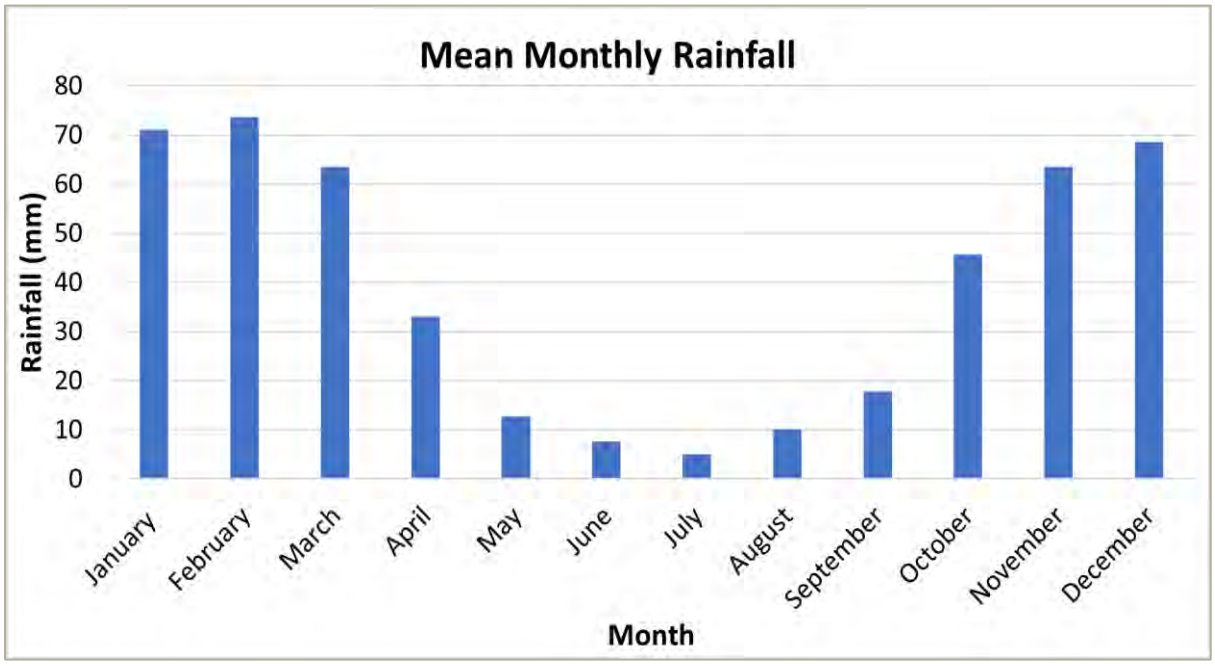


Figure 4-1: Mean Monthly Rainfall for the Area

The storm rainfall depths in the vicinity of Welkom were extracted from the Design Rainfall Estimation in South Africa software programme (Smithers and Schulze, 2002). The programme uses the six closest rainfall stations to a user specified position to calculate the storm rainfall depths. The extracted storm rainfall depths for the project are indicated in Table 4-1.

© 2025 Kongiwe Environmental (Pty) Ltd

Table 4-1: Storm Rainfall Depths for the Area

Storm Duration	Storm Rainfall Depth (mm)						
	1:2 yr	1:5 yr	1:10 yr	1:20 yr	1:50 yr	1:100 yr	1:200 yr
5 min	9	13	15	17	20	23	25
10 min	14	19	22	25	30	33	37
15 min	17	24	28	32	38	42	47
30 min	22	30	35	41	48	53	59
45 min	25	34	40	46	55	61	68
1 hr	28	38	45	51	60	68	75
1.5 hr	32	43	51	59	69	78	86
2 hr	35	48	56	65	76	85	95
4 hr	41	56	66	76	89	100	111
6 hr	45	61	72	83	98	109	121
8 hr	48	65	77	89	104	117	129
10 hr	51	68	81	93	110	123	136
12 hr	53	71	84	97	114	128	142
16 hr	56	76	90	103	122	136	151
20 hr	59	80	94	109	128	143	159
24 hr	62	83	98	113	133	149	165
1 day	51	69	82	94	111	124	138
2 day	63	85	101	116	136	153	169
3 day	71	96	114	131	154	172	191
4 day	77	104	123	142	167	187	207
5 day	82	111	131	151	178	199	220
6 day	87	117	138	159	187	209	232
7 day	90	122	144	166	196	219	242

4.1.2 Evaporation

Evaporation data was sourced from DWA's hydrological dataset (2012). Evaporation data was available between 2000 and 2012, and the average evaporation based on the data is provided in Table 4-2 (Jones & Wagener, 2017). The mean evaporation for 2019 is indicated in Table 4-3.

Table 4-2: Monthly and Annual Evaporation at the Joel Operations (2000 - 2012)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average	189	204	225	215	171	159	119	101	77	88	120	161	1 869
Minimum	92	99	105	100	95	93	82	76	63	57	64	59	997
Maximum	247	274	315	298	244	218	144	138	97	121	150	234	2 197

© 2025 Kongiwe Environmental (Pty) Ltd

Table 4-3: Mean Monthly and Annual Evaporation at the Joel Operations for 2019

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Evaporation	206	163	146	110	86	69	78	107	147	184	202	213	1 711

4.2 Topography

The general topography of the area is described as the Interior Plain of South Africa. According to the terrain morphological division, the area is also described as plains and pans. The topography of the area is undulating, ranging between 1 340m to 1 440m above mean sea level (Figure 4-2). Scattered koppies stand out above the general line of the land surface and drainage lines are slightly incised into the land.

The area of the Operationslopes gently down towards the north, being slightly over 1 460m at the south end of the site, dipping to 1 330m at the north end, giving a gradient of approximately 1:60. The Theronspruit and Doring River lie 15m to 25m and 10m to 15m respectively below the general plateau level.

4.3 Geology

The Free State Goldfield lies some 270km southwest of Johannesburg on the southwest rim of the Witwatersrand Basin. Exploration within the Free State Goldfield dates from the mid-1940s when values within the Basal Reef, the predominant economic reef in the district, were intersected (Figure 4-3). Structurally, the Free State Goldfield lies within a north-south trending syncline forming an apex in the southwestern corner of the Witwatersrand Basin. The northerly plunging syncline is roughly divided by two major faults into three major blocks: the Odendaalsrus section to the west of the De Bron fault, the Central Horst, between the De Bron and Homestead faults and the Virginia Section east of the Homestead Fault. The Central Horst was uplifted and the Central Rand Group rocks eroded away prior to Ventersdorp time.

The Central Rand Group in the Free State comprises some 2 000m of sedimentary sequences deposited over successive unconformity surfaces in an expanding depositional area. The lack of major faulting and folding of Central Rand Group age has led to the conclusion that subtle tectonic warping of the basin with granite doming on the margins-controlled deposition.

The auriferous horizons are most typically conglomeratic units deposited at the base of each depositional sequence, although they may also occur as scours within a given formation. The principal reefs mined in the Free State are the Basal Reef, the Saaiplaas Reef, the Leader Reef, the 'B' Reef, the 'A' Reef, Elsburg Reefs and the Dreyerkuil Reefs.

The Basal Reef is the most extensive, continuous and economically significant reef in the Free State Province, accounting for over one-half of all the gold produced there to date.

The Joel Operation occupies a portion of the Free State goldfield which is located in the south-western part of the Witwatersrand Basin. The Basal Reef is one of numerous gold bearing conglomerates which are intercalated with quartzites and shales in the Central Rand Group of the Witwatersrand Supergroup.

The Witwatersrand sediments, which are approximately 2,7 billion years old , have been tilted and faulted, creating a complex geological structure which is generally regarded as a hindrance to mining. Harmony exploits three auriferous conglomerating horizons, i.e. 'A' Reef, Leader Reef and Basal Reef of the Central Rand Group.

The Witwatersrand rocks are overlain by Ventersdorp lavas and sediments, which in turn, are overlain by younger Karoo rocks.

© 2025 Kongiwe Environmental (Pty) Ltd

The Karoo Supergroup is of the order 330m thick, overlying the lavas and sediments of the Ventersdorp Super group with a marked unconformity. The Ventersdorp Super group consists of the Platberg Group, 0m-760m thick, is formed by debris flow sediments, with diamictites at the bases and shales above. The Kliprivierberg Group lavas (0m-300m thick) are basaltic to andersitic in composition.

The surface geology is composed of Volksrust Shale Formations, and the under lying sandstones of the Vryheid Formation which contain the Upper and Lower Coal Seams. These beds overlay the tilloids of the Dwyka Formation at the base and the Ecca and Beaufort Groups above. The Dwyka Formation consists of 0m-15m thick Tillite, a glacially derived conglomerate set in shale matrix. The Ecca and Beaufort Groups (300m-400m thick) are dominated by shale with thin sandstone units within them.

In certain areas sill intrusions occurred on the plane of the reef but these are limited. Dolerite dykes and sills are common with intrusions of Kimberlite and dioritic rocks being less common. The dolerite intrusions have altered the Karoo sediments by contact metamorphism. These altered sediments have favourable water-bearing characteristics. The dykes seldom have a thickness exceeding 5m, but they may have a length of several kilometres. The sills undulate at various depths with thickness which may exceed 100m .

© 2025 Kongiwe Environmental (Pty) Ltd

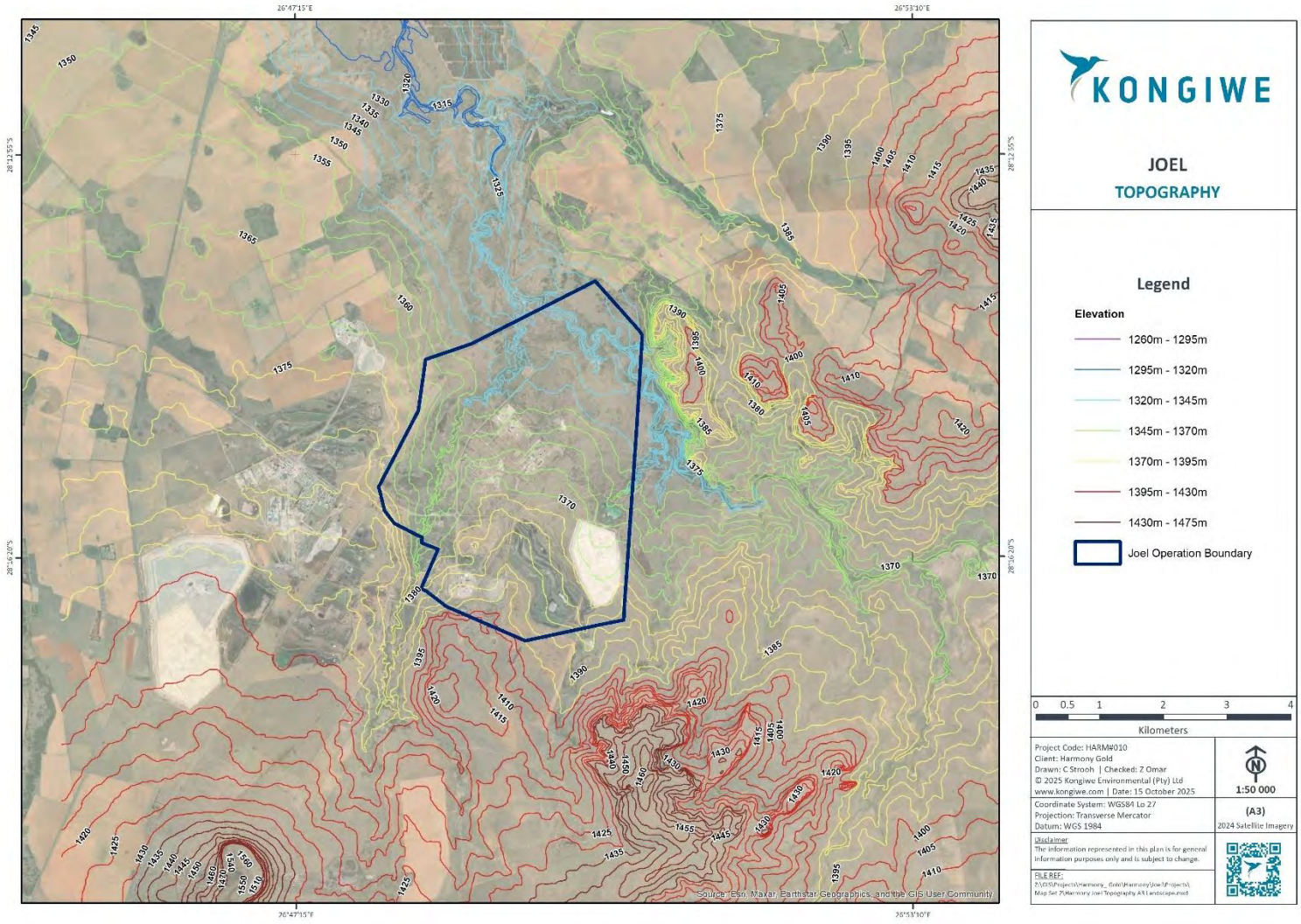


Figure 4-2 Joel Operation Topography

© 2025 Kongiwe Environmental (Pty) Ltd

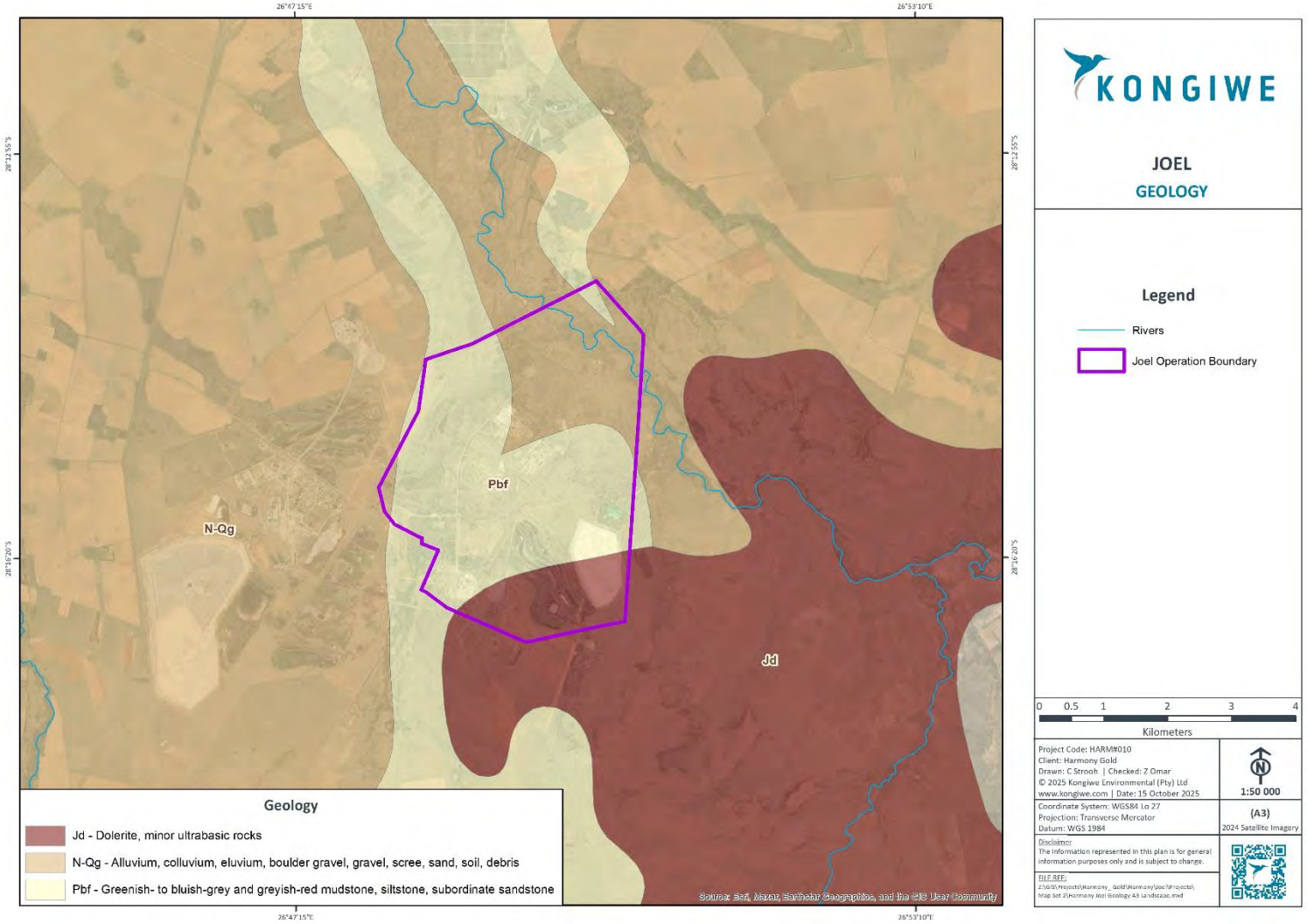


Figure 4-3 Joel Operation Geology

© 2025 Kongiwe Environmental (Pty) Ltd

4.4 Soils, Land Use and Land Capability

The soil within the Harmony Free State Operations can be generalised by the following soil patterns:

- PT2 - Red, yellow and greyish soil with a high base status.
- LP2 - Soil with minimum development, usually shallow, or on hard weathering rock, with or without intermittent diverse soils. Lime generally present in part or most of the landscape.
- CM - Soils with high base status

The area has loamy sands to the north-east and mostly sands present and sub-dominant on the remaining area. Soil clay class is medium, between 15% and 35%. The swell-shrink potential of the clay is mostly low to very low, however moderate to high swell-shrink potential clays are present to the southern part of the area, where Virginia is located. Soils have scarce or absent textural transitions with some transition present to the north-west. Soil depth is high, more than 750mm.

The area has a low to moderate potential for water erosion and susceptible to moderately susceptible to wind erosion due to its sandy nature.

The soils have a high-water holding capacity of 81-100mm deep. Soils are also Eutrophic, meaning low leaching potential. Moderately susceptible soils are strongly dominant. Soils have somewhat impeded drainage to the north and south (Figure 4-4).

Soils have an organic carbon content of 0.5 to 1.0mm and a pH of 6.5-7.4.

The land capability can be summarised as follows: 56% of the land is cultivated and 32% is used for grazing and 12% being classified as incorrectly utilised. The incorrect use of land for cultivation instead of grazing and vice versa is divided approximately evenly so that the present use accurately reflects the agricultural potential of the land. Furthermore, 5,5% of the land in the Goldfields area has had its capability permanently altered, 15% by mining, 10% by infrastructure and 20% by urbanisation.

During the pre-mining period the land on which the mine is now situated was used for grazing and crop planting. Historically, the agricultural production on neighbouring farms consisted of maize crops in summer and wheat in winter, normally planted on a rotational basis. Sunflower crops are alternated with the maize crops on occasion.

Currently the land use on site is dominated by mining and its associated activities. Most of the land cover within the Harmony Free State Operations is classified as mine tailings and resource dumps, commercial annual crops, natural grassland and formal residential areas. As shown in Table 4-4, the land use at the Joel Operation is dominated by mine tailings, natural grassland, and herbaceous wetlands (Figure 4-5).

Table 4-4: Land Cover within Joel Operation

Operation	Land Cover
Joel Operation	Mine: tailings and resource dumps, mines: surface infrastructure, natural grassland, fallow land and old fields (grass), open woodland, herbaceous wetlands.

© 2025 Kongiwe Environmental (Pty) Ltd

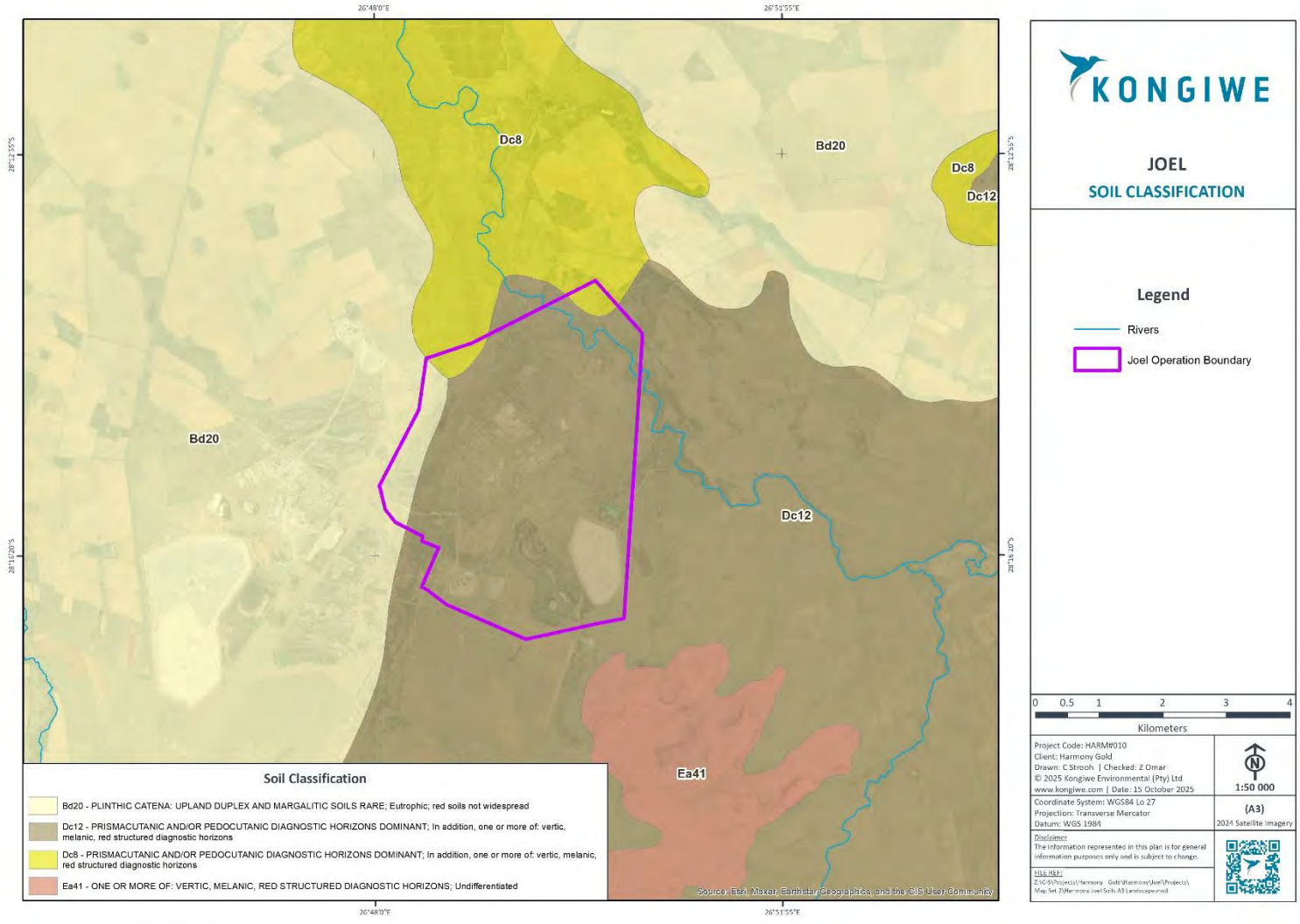


Figure 4-4 Joel Soil Classification Map

© 2025 Kongiwe Environmental (Pty) Ltd

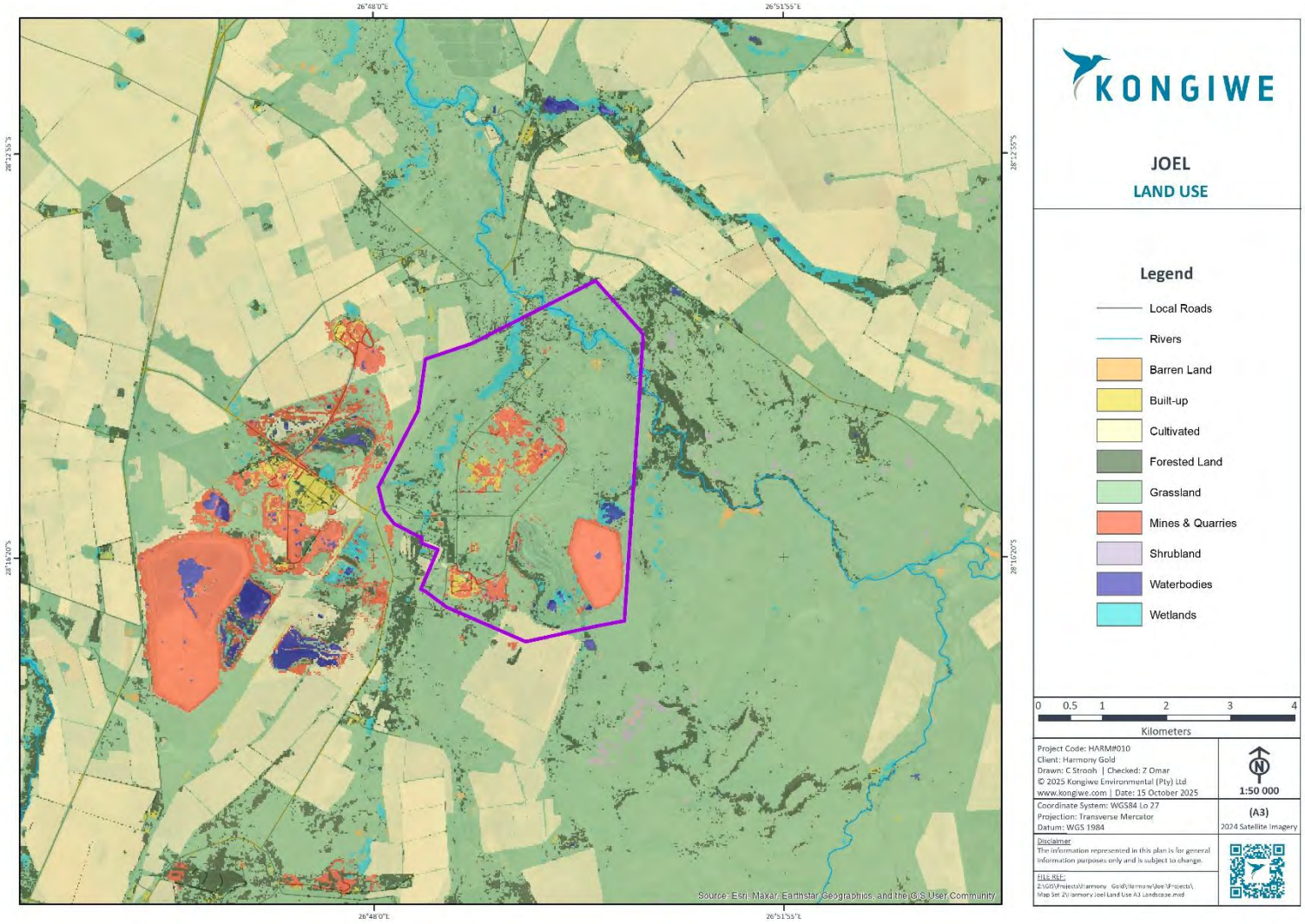


Figure 4-5 Joel Land Use Map

© 2025 Kongiwe Environmental (Pty) Ltd

4.5 Aquatic Biodiversity

Refer to Specialist Study: Appendix B – Water Resource Baseline and Risk Assessment

4.5.1 Status of Sub-quaternary Reach

Desktop information for all Sub-Quaternary Reaches's (SQRs) relevant to the project area was obtained from the DWS (2014). The Desktop Present Ecological State (PES) of these systems is presented in Table 4-5.

The Joel Operation is located in the Free State Province and situated within the Lower Sand River Unit, in the Vaal Water Management Area. The operation is located within quaternary catchment C42K. The desktop PES category of the C42K - 02754 SQR (Doring River) was classed as largely natural (class B).

Table 4-5: Summary of the Present Ecological State of the SQRs Associated with the Joel Operations (DWS, 2014)

SQR	Stream order	Length (km)	PES (DWS, 2014)	Ecological Sensitivity (ES)	Ecological Importance (EI)	Default Ecological Category
Doring River						
C42K - 02754	2	32.57	Largely Natural (class B)	High	Moderate	B
PES-EIS Justification		Minor impacts to instream habitat and connectivity, water quality and flow modifications are small. Very high instream and wetland integrity class and connectivity. Moderate to High sensitivity of aquatic biota to changes in flow and physicochemical modifications. Impacts within the reach are attributed to mining, TSF, agriculture, small dams, and roads.				

4.5.2 Resource Quality Objectives

The NWA sets out to ensure that water resources are used, managed, and controlled in such a way that they benefit all users. To achieve this, the Act has prescribed a series of measures such as Resource Quality Objectives (RQOs) to ensure comprehensive protection of water resources so that they can be used sustainably (DWA, 2011). Results from the riverine assessment are ideally compared to the RQOs of the Water Management Area (WMA), and at a finer level for specific catchments (where available). RQOs provide numerical and/or descriptive statements about the biological, chemical, and physical attributes that characterise a resource for the level of protection defined by its class. "RQOs might describe, among other things, the quantity, pattern and timing of instream flow; water quality; the character and condition of riparian habitats, as well as the characteristics and condition of the aquatic biota". The RQOs for the the quatenary catchment C42K are shown in the table below.

© 2025 Kongiwe Environmental (Pty) Ltd

Table 4-6: Resource Quality Objectives for C42K

Aspect	RQO
C42K	
Doring River	
Target Ecological Category	C/D (Moderately Modified to Largely Modified)
Electrical Conductivity	95th percentile must be less than or equal to 700 µS/cm
pH	5th percentile of 7.5; 95th percentile of 9.2 (7.5 – 9.2)
Target Ecological Category	C/D (Moderately Modified to Largely Modified)
Electrical Conductivity	95th percentile must be less than or equal to 700 µS/cm

4.5.3 In situ Water Quality

An in situ water quality analysis was conducted at all sites assessed that presented adequate surface water during the low flow survey. These results are important to assist in the interpretation of biological results due to the direct influence water quality has on aquatic life forms. Water quality limits were compared to water quality standards provided by DWAF (1996) and the RQOs for the Middle Vaal per relevant catchment, and therefore limits vary between rivers and operations.

The results of the low flow survey for Joel Operation are presented in Table 4-7. An illustration of each site and its associated pH and Electrical Conductivity (EC) as well as the direction of flow has been presented in Figure 4-6 and Figure 4-7, respectively for a special understanding of the complexities of the water quality associated with the Joel Operations. Yellow arrows indicate compliant water quality parameters and red indicate non-compliant parameters.

Table 4-7: In situ Water Quality Results for the Joel Operations (May 2022)

Site	Watercourse Type	pH	Conductivity (µS/cm)	DO (mg/l)	Temperature (°C)
TWQR		**6.5-9.0**	**-**	**>5.00**	**5-30**
Doring River					
RQO		**7.5 – 9.2**	**≤ 700**	*****	*****
SVC 12	River	No Access			
ESW 71	River	DRY			
ESW 82	River	7.78	580	7.30	19.8
ESW 65	River	8.94	1170	4.73	13.70
SVC 04	River	7.80	4110	6.70	13.2
SVC 05	River	8.44	1986	6.53	12.50
Theronspruit					
RQO		**7.5 – 9.2**	**≤ 700**	*****	*****
ESW 79	River	No Access			
ESW 80	River	7.71	7440	4.81	13.1

Levels exceeding recommended guideline levels are indicated in red, * No limit prescribed by relevant legislation

© 2025 Kongiwe Environmental (Pty) Ltd

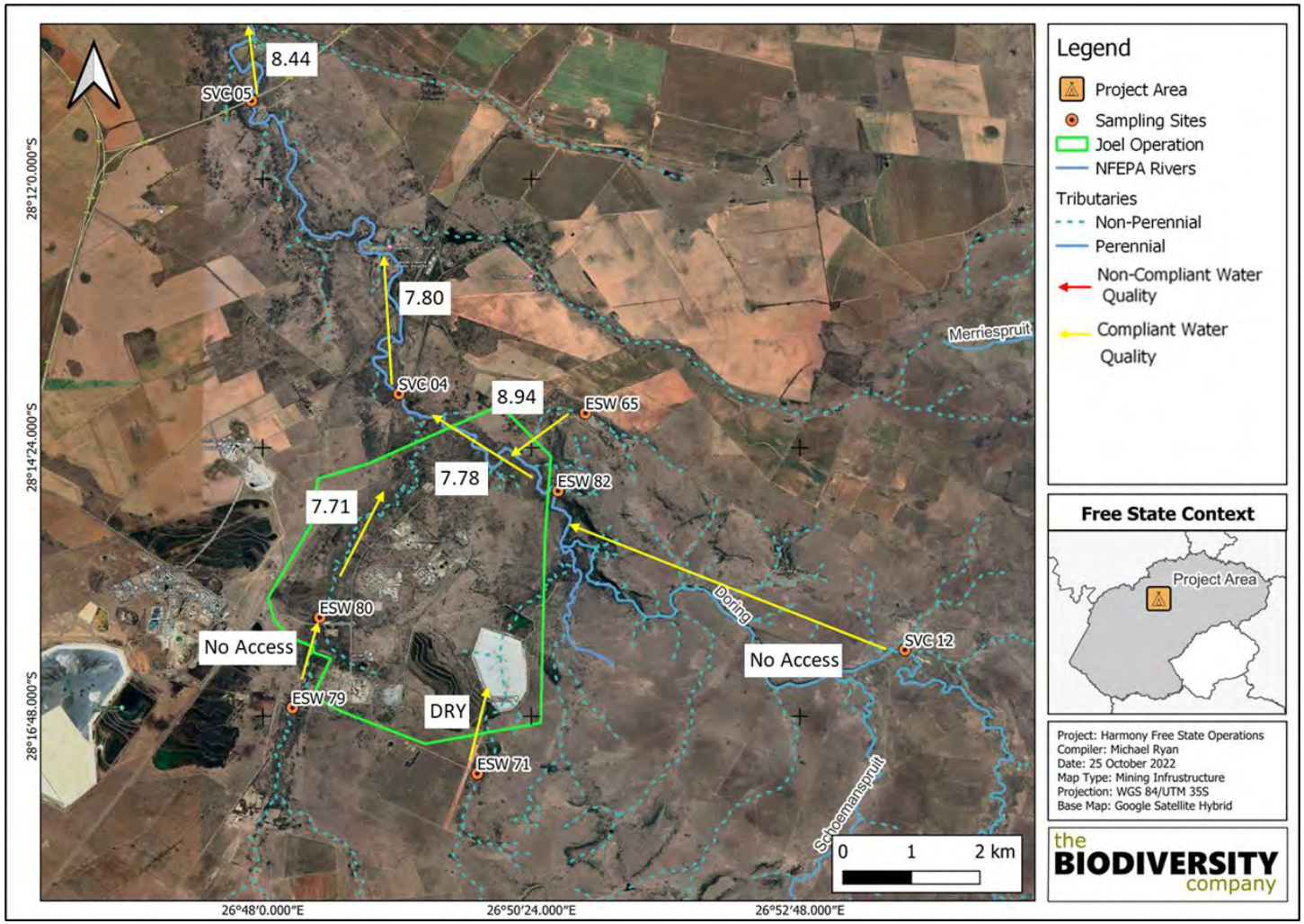


Figure 4-6: pH of Each Site Associated with the Joel Operation

© 2025 Kongiwe Environmental (Pty) Ltd

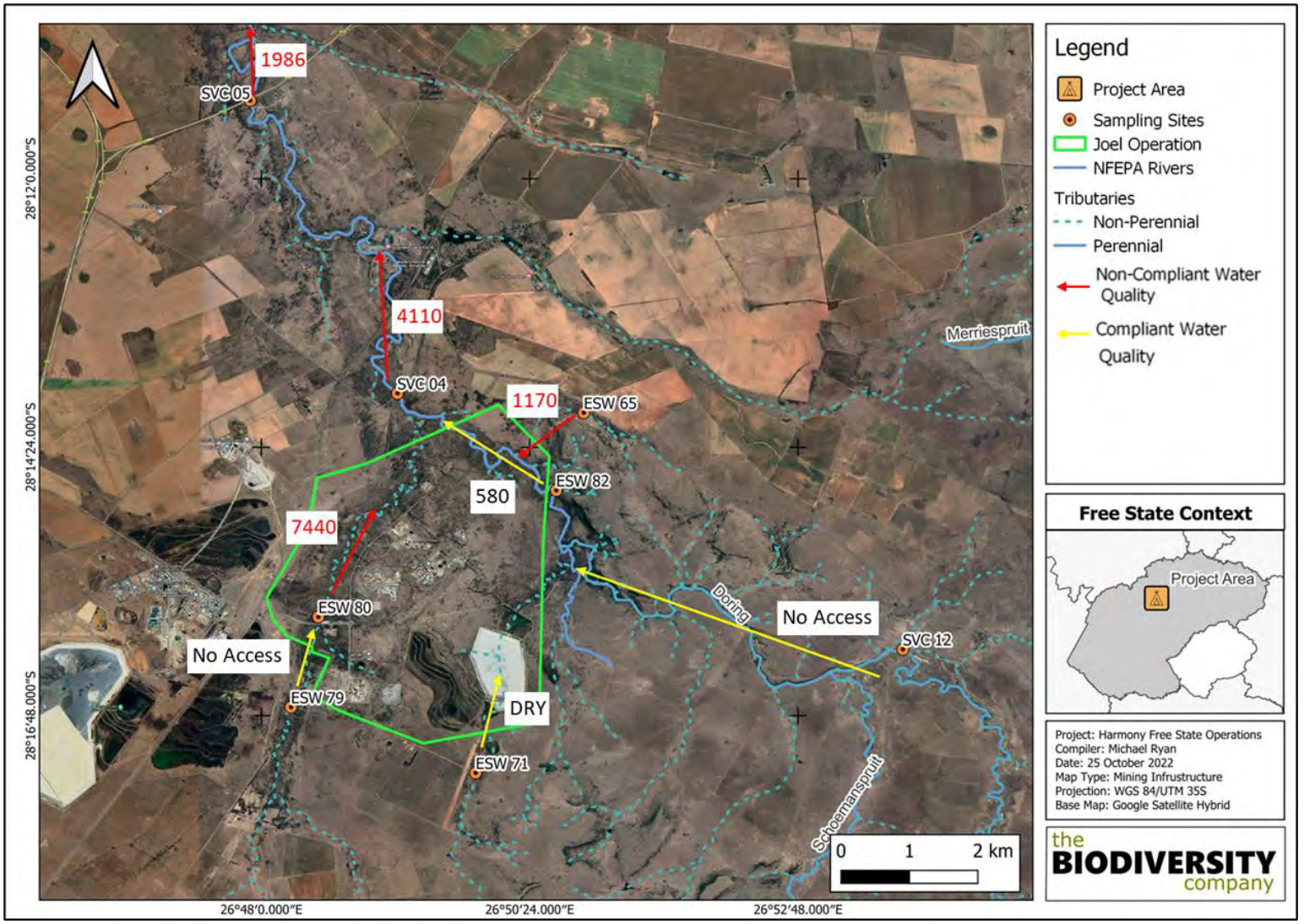


Figure 4-7: EC of Each Site Associated with the Joel Operation

© 2025 Kongiwe Environmental (Pty) Ltd

Water quality data was assessed in one main stem river and one of its tributaries for the Joel Operations a outlined in Table 4-7. The main stem river is the Doring River which follows the north and eastern boundaries of the operation, while the associated tributary known as the Theronspruit follows the western boundary of the operation. The Doring River contains site ESW 82 upstream of the operation and downstream of the Joel TSF and RWD, which is considered natural as all measured parameters are within the prescribed Target Water Quality Range (TWQR) and RQO limits. This then indicates that the TSF and the RWD have not altered the in-stream quality. Site SVC 04 is a downstream site for the Doring River after the confluence with the Theronspruit. The EC was elevated over the RQO limit ≤ 700 µS/cm limit at 4110 µS/cm. Site SVC 05 is a far downstream site and also had an elevated EC of 1986 µS/cm with the decreased concentration of dissolved solids suggested as a result of dilution with multiple tributaries entering between the two sites. The concentration difference between ESW 82 and SVC 04 is suggested to result from either the tributary which ESW 65 is situated along (which is outside of the operations impact), which had an elevated EC of 1170 µS/cm and depleted Dissolve Oxygen (DO) at 4.73 mg/l which is below the TWQR limit of 5.0 mg/l, or the Theronspruit.

The source of the modification to the system is unknown and it cannot be directly attributed to the Joel Operation. The Theronspruit is a more likely a better indicator of modification as the monitoring site ESW 80 is associated with the Joel Operation(south) and the neighbouring Beatrix Mine. This monitoring location had an elevated EC concentration of 7440 µS/cm, as well as a depleted DO concentration of 4.81 mg/l. This can however not be directly attributed to the Joel Operation alone. Various mining activities and other anthropogenic influences attribute to the water quality in the area.

Overall Comments

The pH throughout the watercourses associated with the Joel Operation indicate compliant water quality based on the single parameter. The measured EC however indicates modification. The water quality that is upstream of the Joel Operation water quality is compliant as measured at ESW 82; however, downstream conditions indicate modified conditions in the Doring River. Sources of modification include the tributary ESW 65 but the significant influence, as measured by ESW 80, is from the Theronspruit which indicates modification from the mining activity of the neighbouring Beatrix Mine and Joel Operation. Water quality within the Doring River and Theronspruit is considered to be a limiting factor for aquatic biodiversity due to elevated EC in both systems.

4.5.4 Intermediate Habitat Integrity Assessment

The Doring River originates from the south of the Joel Operation and water from this river flows into the Sand River located approximately 19 km to the northwest of the mining operations. The results of the instream and riparian habitat assessment for the Doring River indicated a category D or largely modified habitat conditions. This indicates that a large loss of natural habitat, biota and basic ecosystem functions has occurred in both the instream and riparian habitat. The ecological condition of the watercourse was derived to be within the recommended management C/D (moderately modified to largely modified) of the RQOs for the catchment (Table 4-8). The identified dominant contributors to the modified state of the system are a result of the surrounding Joel Operation and Beatrix Mine, as well as some agricultural activities which have resulted in some water quality modification through nutrient runoff.

The tributaries have some small dams with water abstraction used for agricultural irrigation. Channel modification is dominated by road crossings that hinder natural river migrations of meanders, as well as small scale encroachment by agriculture and mining.

The river system has also experienced significant bank erosion which has resulted in bed modification as eroded material causes sedimentation of the systems, compounded by dryland agricultural activities. It is therefore clear

© 2025 Kongiwe Environmental (Pty) Ltd

that modification of the Doring River is from cumulative influences which cause compounding impacts that collectively contribute to the altered quality of habitat.

Table 4-8: Results for the Doring River Habitat Integrity Assessment

Instream	Average Score	Impact Score
Water abstraction	10	5.6
Flow modification	19	9.88
Bed modification	16	8.32
Channel modification	15	7.8
Water quality	17	9.52
Inundation	10	4
Exotic macrophytes	6	2.16
Exotic fauna	5	1.6
Solid waste disposal	4	0.96
Total Instream		**50.16**
Category		**D**
Riparian	**Average Score**	**Impact Score**
Indigenous vegetation removal	16	8.32
Exotic vegetation encroachment	10	4.8
Bank erosion	15	8.4
Channel modification	17	8.16
Water abstraction	10	5.2
Inundation	11	4.84
Flow modification	15	7.2
Water quality	16	8.32
Total Riparian		**44.76**
Category		**D**

4.5.5 Aquatic Macroinvertebrates

The sampled river reaches generally presented a low to moderate diversity of biotopes and hydraulic habitat variations. Therefore, a moderate macroinvertebrate community diversity would be expected in the sampled systems, namely Theronspruit and its tributaries. This included some sites on the Doring rivers Table 4-9.

Table 4-9: Biotope Diversity Scores for the May 2022 Assessment Continued

Site	Doring River				Theronspruit
	ESW 82	SVC 04	SVC 05	SVC 7	ESW 80
Geoclass	E				-
Stones in current	4	3	3	2.5	3
Stones out of current	3	2	2	0	1
Bedrock	1	1	0	2	0

© 2025 Kongiwe Environmental (Pty) Ltd

Site	Doring River				Theronspruit
	ESW 82	SVC 04	SVC 05	SVC 7	ESW 80
Aquatic Vegetation	2	0	1	2	0
Marginal Vegetation In Current	4	2	2	3	3
Marginal Vegetation Out Of Current	3	2	3	0	1
Gravel	5	4	2	3	4
Sand	4	4	3	3	4
Mud	2	2	1	4	3
Total Score (X / 45)	28	20	17	19.5	19
Weighted Biotope Score (%)	70	51	46	36	45
Biotope Category (Tate and Husted, 2015)	B	C	D	E	D

4.5.6 South Africa Scoring System

The South African Scoring System Version 5 (SASS5) scores recorded for the Joel Operation ranged from 62 at ESW 80 (Theronspruit) to 188 at ESW 82 (Doring River) (Table 4-10). The number of sampled taxa indicated that the Doring system had a moderate diversity of aquatic macroinvertebrates ranging from 23 at SVC 04 and SVC 05 to 35 at ESW 82. The Theronspruit had a lower and depauperate diversity at 13 taxa. The average sensitivity scores indicated that the sampled river reaches comprised primarily of pollution-tolerant macroinvertebrate taxa ranging from 4.3 at SVC 05 to 5.4 at ESW 82, with a low diversity of semi-intolerant taxa resulting in slightly higher Average Score Per recorded Taxon (ASPT) values compared to the larger project area. The biotic integrity of the sampled sites ranged from Natural (category A) to Moderately Modified (category C). This indicates that the macroinvertebrate assemblages are in a stable condition. Despite the stable conditions, these two systems have water quality (dissolved solid concentrations) and moderate habitat/ habitat disturbances influencing the community structures. It should be noted that the macroinvertebrate community (based on ASPT scores) in the Doring River deteriorated in downstream direction which coincides with the location of sites, upstream (ESW 82), midstream (SVC 04) and downstream (SVC 05) of the anthropogenic catchment impacts which includes mining present in the reach from both the Beatrix Mine and the Joel Operation.

Table 4-10: Macroinvertebrate Assessment Results Recorded for the Joel Operations

Site	SASS5 Score	No. of Taxa	ASPT*	Category	Comment
Doring River					
ESW 82	188	35	5.4	A	Adequate water quality. Diverse habitat (70%)
SVC 04	107	23	4.7	B	High salts. Moderate habitat (51%)
SVC 05	100	23	4.3	B	High salts. Moderate habitat (46%)

© 2025 Kongiwe Environmental (Pty) Ltd

Site	SASS5 Score	No. of Taxa	ASPT*	Category	Comment
Theronspruit					
ESW 80	62	13	4.8	C	High salts & slightly low dissolved oxygen. Moderate habitat (45%)

4.5.7 Macroinvertebrate Response Assessment Index (MIRAI) Results

The MIRAI results for the Doring River (sites ESW 82, SVC 04, SVC 05 & SVC 07) (SVC 07 is located further downstream before the Doring river flows into the Sand River) derived an EC of largely modified (category D) which fell slightly short of the Target Ecological Category (TEC) for the catchment. All three drivers were largely modified contributing to the modified macroinvertebrate communities. The absence of tolerant and water quality sensitive taxa such as *Aeshnidae* (Hawkers & Emperor Dragonflies) and *Leptophlebiidae*, among other common missing taxa, confirms the modified water quality in the Doring River. The sensitive taxa collected included *Atyidae* (Freshwater Shrimp – sensitivity score 8), *Baetidae* >2 sp (Mayflies - 12), Corduliidae/ Macromiidae (Cruiser Dragonflies) and *Hydropsychidae 2 sp* (Caddisflies - 6), notably in the upper reaches (ESW 82) and not at the midstream and downstream sites. The results indicate that this downstream deterioration can be attributed to contaminated water from the midstream tributary system (Theronspruit in Table 4-10) and downstream tributaries. The Doring River ecological drivers have cumulatively been subjected to catchment and channel alteration for land use similar to the Sand River, with mining in the upper reaches and along the tributaries. To avoid further deterioration responsible management of the catchment and watercourse habitat of this river and its tributaries is required.

Table 4-11: MIRAI Score for the Sampled Systems (Main Stems)

Invertebrate Metric Group	Doring
Sites	ESW 82 SVC 04 SVC 05 SVC 07
Flow Modifications	50.6
Habitat	56.3
Water Quality	53.8
Ecological Score	53.7
Category	D
MIRAI RQO	-
TEC RQO	C/D

4.5.8 Fish Community Assessment

Cover features sampled within the Doring River were limited and would contribute to the absence of several species as only three indigenous species were collected that have high preference for standing waters. The presence of instream impoundments within the Doring River would limit migration and the presence of several species in the upper reaches and no indigenous species were collected within the reach. A single exotic species

© 2025 Kongiwe Environmental (Pty) Ltd

was collected, *G. affinis* at site SVC 6. No fish were collected within the Theronspruit. Low flows and poor water quality contribute to adverse conditions to aquatic biota.

The Doring river was classed as seriously modified (Category E). The diversity of hydraulic biotopes and cover features were limited within the system and were a limiting factor to the fish community, however, only three species were collected in the reach with a low frequency of occurrence. Water quality perturbations within the Doring further reduced the biotic integrity.

No indigenous fish species were collected within the Theronspruit. This site was rated as seriously modified (Category E), and the absence of fish was attributed to various site-specific modifications (i.e. poor cover features) and catchment level impacts, including numerous impoundments restricting migration.

Table 4-12: Presence/ Absence of Fish Species for the Sampled Sites and Fish Response Assessment Index (FRAI) Results per Reach

Site	Doring River				Theronspruit
	ESW 82	SVC 04	SVC 05	SVC 7	ESW 80
Austroglanis sclateri	-	-	-	-	-
Clarias gariepinus	-	-	-	1	-
Enteromius anoplus	-	-	-	-	-
Enteromius paludinosus	-	-	-	-	-
Gambusia affinis	-	-	-	1	-
Labeo capensis	-	-	-	-	-
Labeo umbratus	-	-	-	-	-
Labeobarbus aeneus	-	-	-	-	-
Pseudocrenilabrus philander	-	-	1	-	-
Tilapia sparrmanii	1	-	1	-	-
Total	**1**	**0**	**2**	**2**	**0**
Expected	**7**	**9**	**9**	**9**	**4**
% Community Collected	**14**	**0**	**22**	**22**	**0**
FRAI Score and Category	31% Category E				20% Category E

Species in red indicate alien invasives

4.5.9 Present Ecological State

The Doring River experienced modified water quality with largely modified riparian areas. This resulted in largely modified macroinvertebrate communities and modified fish communities. The Doring River was determined to have a largely modified Ecostatus. This indicates that the river systems associated with the Harmony Free State Operations have experienced modification with a key factor resulting in compounding impacts and the degradation of water quality in the systems.

Table 4-13: The Present Ecological Status of the Rivers Pertaining to the Harmony Free State Operations

Category	Score	Ecological Category
	Doring River	
Riparian	44.76	D
Macroinvertebrate	45.2	D

© 2025 Kongiwe Environmental (Pty) Ltd

Fish Assemblage	31	E
Ecostatus	42.09	
	Largely Modified (category D)	

4.6 Wetlands

Refer to Specialist Study: Appendix B – Water Resource Baseline and Risk Assessment

4.6.1 Wetland Indicators

According to (DWAF, 2005), a combination of hydromorphic soils and hydrophytic plants must be used to identify and accurately delineate wetland areas.

Hydromorphic Soils

According to (DWAF, 2005), soils are the most important characteristic of wetlands to accurately identify and delineate wetland areas. Five dominant soil forms were identified within the identified wetland, namely the Katspruit, Kroonstad, Longlands, Westleigh and Mispah soil forms (Soil Classification Working Group, 2018).

The Katspruit soil form consists of an orthic topsoil on top of a gleyic horizon. The "2210" family group is applicable to this soil form given the grey colours, the firm texture and structure of the soil form and the absence of lime.

The Kroonstad soil form consists of an Orthic topsoil on top of an Albic horizon, which in turn is underlain by a Gleyic horizon. The soil family group identified for the Kroonstad soil form is "1110" due to the gleyed colour of the topsoil, the Albic horizon's grey colours when in a wet condition as well as the non-calcareous nature of the soil.

The Longlands soil form consists of an orthic topsoil on top of an albic horizon. The soil family group identified for the Longlands soil form on-site has been classified as the "1000" soil family due to the grey colour of the soil in wet conditions.

The Westleigh soil form consists of an Orthic A-horizon on top of a Soft Plinthic B-horizon. The soil family group identified for the Westleigh soil form on-site has been classified as the Helena (1000) soil family given the lack of evidence pertaining to luvic processes.

The Mispah soil form consists of an orthic topsoil on top of a hard rock layer. The soil family group identified for the Mispah soil form on-site is that of 2120 due to the chromic properties of the topsoil, the absence of lime as well as the solid structure of the bedrock.

Orthic topsoils are mineral horizons that have been exposed to biological activities and varying intensities of mineral weathering. The climatic conditions and parent material ensure a wide range of properties differing from one orthic topsoil to another (i.e., colouration, structure etc.) (Soil Classification Working Group, 2018).

Albic horizons are often characterised by uniform white-greyish colours from the residual clay and quartz particles making up the matrix of the horizon. The main characteristic of this diagnostic horizon is a bleached colouration, which is a resultant product of distinct redox and ferrolysis pedological processes combined with eluvial processes. According to the Soil Classification Working Group (2018), albic horizons often receive lateral sub-surface flows from hillslope processes.

Gley horizons that are well developed and have homogenous dark to light grey colours with smooth transitions. Stagnant and reduced water over long periods is the main factor responsible for the formation of a gley horizon

© 2025 Kongiwe Environmental (Pty) Ltd

and could be characterised by green or blue tinges due to the presence of a mineral called Fougerite which includes sulphate and carbonate complexes. Even though grey colours are dominant, yellow and/or red striations can be noticed throughout a gley horizon. The structure of a gley horizon mostly is characterised as strong pedal, with low hydraulic conductivities and a clay texture, although sandy gley horizons are known to occur. The gley soil form commonly occurs at the toe of hillslopes (or benches) where lateral water inputs (sub-surface) are dominant, and the underlying geology is characterised by a low hydraulic conductivity. The gley horizon usually is second in diagnostic sequence in shallow profiles yet is known to be lower down in sequence and at greater depths (Soil Classification Working Group, 2018).

The accumulations of iron (and in some cases manganese) as hydroxides and oxides with the presence of high chroma striations and concretions with black matrixes are associated with the Soft Plinthic horizon. This diagnostic horizon forms due to fluctuating levels of saturation. The iron and manganese concentration result in soft marks within the soil matrix which transform in concretions with high consistencies (Soil Classification Working Group, 1991).

If this process continues for long enough periods, a massive continous impermeable layer of hard plinthite forms. A Soft Plinthic horizon and a Hard Plinthic horizon can be distinguished from one another by means of a simple spade test. A Soft Plinthic horizon can be penetrated by means of a spade in wet conditions whereas a Hard Plinthic horizon cannot (Soil Classification Working Group, 1991).

According to Soil Classification Working Group (2018), this horizon commonly occurs as a result of hillslope hydrology in flat, sandy landscapes. This horizon is known to have an apedal structure together with the presence of concretions. The hard rock layer disallows infiltration of water or root systems and occur in shallow profiles. Horizontally layered, hard sediments without evidence of vertical seems fall under this category.

Hydrophytes

Vegetation plays a considerable role in identifying, classifying and accurately delineating wetlands (DWAF, 2005). During the site visit, various hydrophytic species were identified (including facultative species). Examples include Cyperus spp,. Persicaria spp., Typha Capensis.

4.6.2 General Functional Description of Wetland Types

Channelled valley bottom wetlands tend to contribute less to sediment trapping and flood attenuation than other systems. Channelled valley bottom wetlands are well known to improve the assimilation of toxicants, nitrates and sulphates, especially in cases where sub-surface flows contribute to the system's water source (Kotze et al., 2009).

Hillslope seeps are well documented by Kotze et al. (2009) to be associated with sub-surface ground water flows. These systems tend to contribute to flood attenuation given their diffused nature. This attenuation only occurs while the soil within the wetland is not yet fully saturated. The accumulation of organic material and sediments contributes to prolonged levels of saturation due to this deposition slowing down the sub-surface movement of water. Water typically accumulates in the upper slope (above the seep). The accumulation of organic matter additionally is essential in the denitrification process involved with nitrate assimilation. Seeps generally also improve the quality of water by removing excess nutrient and inorganic pollutants originating from agricultural, industrial, or mining activities. The diffuse nature of flows ensures the assimilation of nitrates, toxicants and phosphates with erosion control being one of the Eco Services provided by the wetland given the nature of a typical seep's position on slopes.

Unchannelled valley bottoms are characterised by sediment deposition, a gentle gradient with streamflow generally being spread diffusely across the wetland, ultimately ensuring prolonged saturation levels and high levels of organic matter. The assimilation of toxicants, nitrates and phosphates is usually high for unchannelled

© 2025 Kongiwe Environmental (Pty) Ltd

valley-bottom wetlands, especially in cases where the valley is fed by sub-surface interflow from slopes. The shallow depths of surface water within this system adds to the degradation of toxic contaminants by means of sunlight penetration.

It is however important to note that the descriptions of the above-mentioned functions are merely typical expectations. All wetland systems are unique and therefore, the ecosystem services rated high for these systems on site might differ slightly to those expectations.

4.6.3 Wetland Delineation Within Joel Operation

Four different wetland types, comprising numerous individual hydrogeomorphic (HGM) units were delineated in accordance with the DWAF (2005) guidelines. The four different types were classified as being channelled valley bottoms, unchannelled valley bottoms, hillslope seeps and depression wetlands.

The channelled valley bottom wetland is located on the “valley floor” landscape unit. Channelled valley bottom wetlands are typically found on valley-floors with a clearly defined, finite stream channel and lacks floodplain features, referring specifically to meanders. Channelled valley bottom wetlands are known to undergo loss of sediment in cases where the wetlands’ slope is high and the deposition thereof in cases of low relief. Depression wetlands are typically located on the “valley-floor” landscape unit.

The unchanneled valley bottom is located on the “valley floor” landscape unit. Unchanneled valley bottom wetlands are typically found on valley-floors where the landscape does not allow high energy flows. Hillslope seeps are located within slopes. Isolated hillslope seeps are characterised by colluvial movement of material. These systems are fed by very diffuse sub-surface flows which seeps out at very slow rates, ultimately ensuring that no direct surface water connects this wetland with other water courses within the valleys.

Depressions are inward draining basins with an enclosing topography which allows for water to accumulate within the system. Depressions, in some cases, are also fed by lateral sub-surface flows in cases where the dominant geology allows for these types of flows.

According to (DWAF, 2005), a combination of hydromorphic soils and hydrophytic plants must be used to identify and accurately delineate wetland areas. Five dominant soil forms were identified within the identified wetland, namely the Katspruit, Kroonstad, Longlands, Westleigh and Mispah soil forms. A wetland delineation map has been created and illustrates the wetlands on site at the Joel operations (Figure 4-8). Channelled Valley Bottom and Unchannelled Valley Bottom wetland types are found in Joel Operation.

© 2025 Kongiwe Environmental (Pty) Ltd

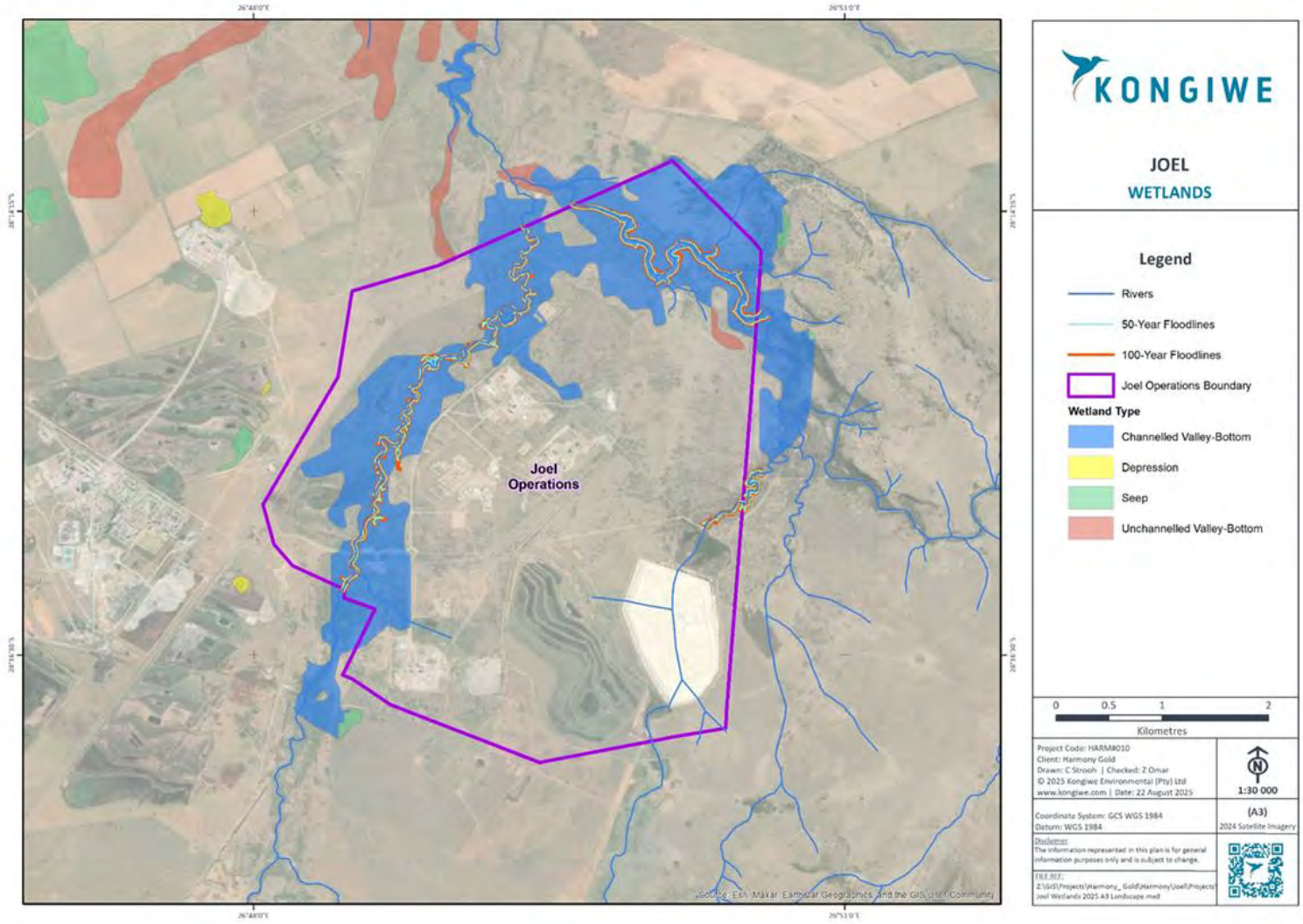


Figure 4-8 Composite Wetland Delineation Map for the Joel Operations

© 2025 Kongiwe Environmental (Pty) Ltd

4.7 Flora

According to JPH Acocks – veld types of South Africa – the Harmony Free State Operations are situated in the area classified by Acocks as "The dry Cymbopogon – Themeda veld". This veld type occurs between the Vaal and the Orange Rivers, as far south as Bloemfontein, mostly on sandy soils.

According to Mucina and Rutherford's Vegetation biomes, the area to the north falls within the Western Free State Clay grassland (Gh9 & AZi10). This vegetation biome is restricted to flat bottomlands which support dry, species-poor grassland with a high number of salt pans (playas) embedded. Dwarf karoo shrubland surround the playas in disturbed habitats.

The largest part of the area falls in the Vaal-Vet Sandy Grassland (Gh10) according to Mucina and Rutherford. This area is characterised by plains-dominated landscape with some scattered, slightly irregular undulating plains and hills. Mainly low-tussock grassland with an abundant karroid element. Dominance of Themeda triandra is an important feature of this vegetation unit.

In the riverine areas it falls in the Highveld Alluvial Vegetation (AZa5) according to Mucina and Rutherford. This area is characterised by a flat topography supporting riparian thickets mostly dominant by Acacia karoo, accompanied by seasonal flooded grasslands and disturbed herblands often dominated by alien plants.

Species of general occurrence in the Dry Cymbopogon–Themeda veld type include:

- *Themeda triandra.*
- *Aristida congesta.*
- *Eragrostis lehmanniana.*
- *Eragrostis suerba.*
- *Cynodon dactylon.*
- *Seteria flabellate.*

The importance of Aristida congesta subspecies Congesta, Eragrostis lehmanniana and Tragus koeleriodes shows the more arid nature of this veld.

4.8 Fauna

The wildlife in the general area on and around the mining area has been severely impacted on by development and surrounding activities. Most of the large mammal species do not occur in the area, although the biodiversity of the area has been boosted by the creation of artificial wetlands, gardens and other habitats associated with the mines and their infrastructure. 214 Species of bird life have been identified.

The habitat suitability for Red Data species is low for all species within the study sites investigated for the purposes of this report. This is mainly due to the fact that the area is highly disturbed due to mining activities.

4.9 Surface Water

Refer to Specialist Study: Appendix D – Surface Water Study

The DWS has divided South Africa into primary, secondary, tertiary and quaternary catchments. Primary catchments are the largest defined catchments for South Africa, of which there are 22, and are assigned a letter ranging from A – X (excluding O). Secondary catchments are subdivisions of the primary catchments, are the second largest catchments in South Africa and are assigned the primary catchment letter within which they are

© 2025 Kongiwe Environmental (Pty) Ltd

located, and a number e.g. A5 (secondary catchment 5 located within primary catchment A). Similarly, tertiary catchments are subdivisions of secondary catchments and are represented for example by A53 (tertiary catchment 3 located within secondary catchment A5). Lastly, quaternary catchments are the smallest defined catchments and are assigned the tertiary catchment number, along with a quaternary catchment letter e.g. A53D (quaternary catchment D located within tertiary catchment A53).

Further to the above, the DWS has divided South Africa into six Water Management Areas (WMAs). The 6 WMAs comprise the Limpopo- Olifants, Pongola-Umzimkhulu, Mzimvubu-Tsitsikamma, Breede-Gouritz and Berg-Olifants.

The Harmony Free State Operations are located within the Vaal River Catchment area. The surface water drainage across the Harmony Free State Operations is mainly from the southeast towards the northwest.The main stem river in the proximity of the Joel Operation is the Doring River which follows the north and eastern boundaries of the operation, while the associated tributary known as the Theronspruit River follows the western boundary of the operation. These are the two main rivers associated with the Joel Operation.

4.9.1 Water Management Area

The Joel Operation is located in the Free State Province and situated within the Lower Sand River Unit, in the Vaal Water Management Area. The operation is located within quaternary catchment C42K.

4.9.2 Surface Water Hydrology

The Doring River runs from the east to the north-east of the Joel Operation. The Doring River originates from the south of the Joel Operations and water from this river flows into the Sand River located approximately 19 km to the north-west of the operations. Surface runoff generated at the Joel Operation is directed from the south-east towards the north-west to the river (Hydrospatial,2023).

4.9.3 Surface Water Quality

Surface water quality monitoring began in the 1980s. The current monitoring points are presented in Table 4-14. The site currently does not have any water quality standards that are applicable to them as they do not have a WUL. The site currently makes use of available standards as guidelines and will implement the official applicable standards once the WUL has been approved and the relevant applicable standards have been provided. Water quality limits that apply to the Joel Operation are presented in Table 4-15.

It must be noted that the water quality of the stream surrounding the Joel Operation has been impacted by the historic mining activities and other anthropogenic influences. This must be kept in mind when the various limits for monitoring are determined.

Water quality is assessed on a monthly and quarterly basis. The monitoring programme is updated annually and submitted to the Regional Head for approval with the annual report.

Table 4-14: Surface Water Quality Monitoring Program

Site	Description	Latitude	Longitude	Frequency
Monthly Instream Surface Water Sample Location				
ESW 80	Theronspruit upstream	S 28° 15’ 55.00’’	E 26° 48’ 30.60’’	Monthly
ESW 81	Theronspruit downstream	S 28° 14’ 34.90’’	E 26° 49’ 18.80’’	Monthly
ESW 82	Doring River upstream of RWD inflow	S 28° 15’ 34.92’’	E 26° 50’ 54.67’’	Monthly
ESW 83	Doring River before confluence with Theronspruit	S 28° 14’ 17.83’’	E 26° 49’ 54.30’’	Monthly

© 2025 Kongiwe Environmental (Pty) Ltd

Site	Description	Latitude	Longitude	Frequency
Monthly Instream Surface Water Sample Location				
ESW 67	Upstream from JSW, Downstream from Sibanye	S 28° 14’ 44.46’’	E 26° 49’ 23.87’’	Monthly
ESW 71	Joel/ Doringspruit North of Joel 1 shaft	S 28° 11’ 18.7’’	E 26° 47’ 52.6’’	Monthly
ESW MOJ1	Main office/proto office dam	S 28° 16' 20.01"	E 26° 48' 53.51"	Monthly
ESW JSW1	Joel Sewage Plant Effluent to Theronspruit	S 28° 14' 43.91”	E 26° 49' 30.09"	Monthly
Quarterly Process Water Containment (Dirty Water) Dams Water Sample Locations				
ESW 68	Joel Return Water Dam	S 28° 15' 58.46"	E 26° 50' 16.27"	Quarterly
ESW 69	Joel Evaporation Dam	S 28° 16’ 45.37’’	E 26° 50’ 08.58’’	Quarterly
ESW 70	Joel Dam at shooting range	S 28° 17’ 00.26’’	E 26° 50’ 07.99’’	Quarterly
ESW TK1	Joel 3 Shaft TK1 water tank	28°16'34.64"S	26°48'43.64"E	Quarterly
New Joel 1	Joel 1 Shaft Silt Trap	S 28° 15’ 12.34’’	E 26° 49’ 23.83’’	Quarterly
New Joel 3	Joel 3 Shaft Storm Water Dam	S 28° 16’ 26.31’’	E 26° 48’ 45.37’’	Quarterly

Table 4-15: Surface Water Quality Guidelines and Standards

Parameter	Limit	Unit	Source
pH	6.5-8.5	pH	RQO 2016
EC	65	mS/m	RQO 2016
TDS	1000	mg/L	SAWQG 1996 – V5 Livestock
NH3	1.5	mg/L	SANS 241:2015
Cl	1500	mg/L	SAWQG 1996 – V5 Livestock
NO2	100	mg/L	SAWQG 1996 – V5 Livestock
PO4	0.058	mg/L	RQO 2016
SO4	1000	mg/L	SAWQG 1996 – V5 Livestock
U	0.01	mg/L	SAWQG 1996 – V4 Irrigation
TON		mg/L	

SAWQG – South African Water Quality Guidelines

It is recommended that pH, EC, TDS, SS, T.Alk, Cn WAD, SO4 PO4, NO3, NH3, F, Cl, Na, Ca, Mg, K, Al, Fe, Mn, Ni, Pb, U & Zn be sampled at the monitoring locations. The site currently makes use of available standards as guidelines and will implement the official applicable standards once the WUL has been approved and the relevant applicable standards have been provided.

To accurately monitor the quality of the surrounding surface water, it is advised that relevant parameters be applied to rivers and streams and not to the various process water dams. This must be kept in mind by the DWS when the various limits are being determined.

© 2025 Kongiwe Environmental (Pty) Ltd

Process water containment facilities must be excluded from the prescribed instream water quality standards, as process water facilities won't be able to comply with instream water quality standards.

4.9.4 Mean Annual Runoff

The mean annual runoff for the Lower Sand River (Rietspruit Tributary) catchment area is 180.27 million m^3 (DWS, 2016) and the proposed Reserve indicated the mean annual runoff for quaternary catchment C42K as 140.67 million m^3 (DWS, 2018).

4.9.5 Floodlines

The floodlines and 100 m buffers have been determined for the rivers and streams that flow through the Joel Operation. These include:

- The Doring River which flows in a north-westerly direction near the north-eastern boundary of the operation.
- The Theronspruit that flows in a north-easterly direction on the western side of the operations.
- A non-perennial stream (Tributary 1) that flows in a north-easterly direction along the eastern boundary of the operations. This stream is a tributary of the Doring River. The TSF Complex and RWD have been constructed within this stream.

A summary of the estimated peak flows that were used to determine the floodlines is provided in Table 4-16, whilst the floodlines and 100 m river buffers are shown on Figure 4-9.

Table 4-16: Peak Flows Used to Determine the Floodlines for the Joel Operations

River	Catchment Area (km^2)	Method	1:50 Year Peak Flow (m^3/s)	1:100 Year Peak Flow (m^3/s)
Doring River	250.2	Rational	214	289
		SCS	224	278
		Midgley & Pitman	230	291
		Average	**223**	**286**
Theronspruit	47.3	Rational	88	118
		SCS	96	118
		Midgley & Pitman	93	117
		Average	**92**	**118**
Tributary 1 of Doring River	12.8	Rational	25	47
		SCS	39	48
		Midgley & Pitman	40	50
		Average	**35**	**48**

The RWD and TSF Complex have been constructed within a non-perennial tributary of the Doring River and therefore located within 100 m of a river. A clean water channel/diversion has been constructed upstream to the south of the TSF Complex.

© 2025 Kongiwe Environmental (Pty) Ltd

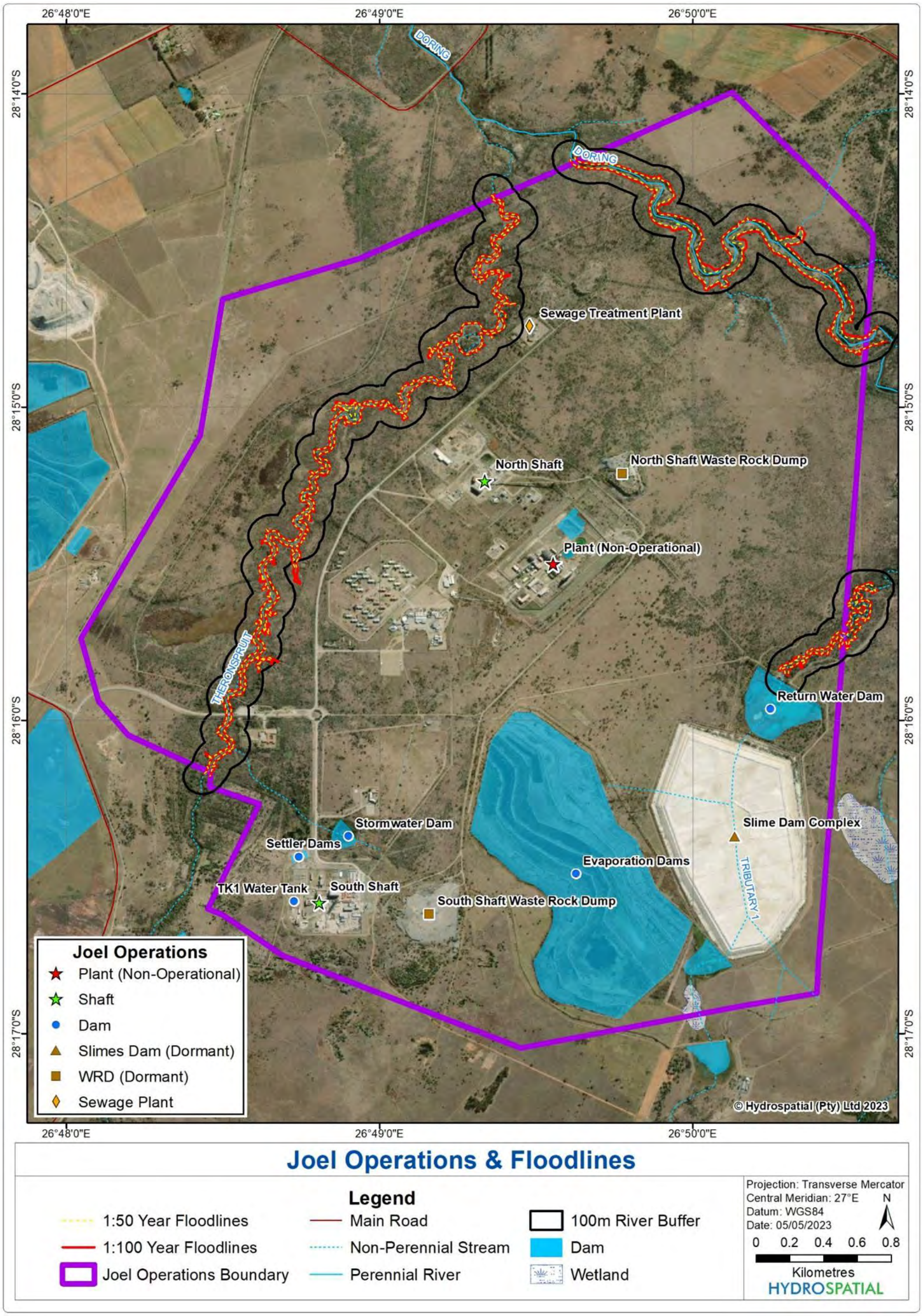


Figure 4-9: Joel Operations and Floodlines

© 2025 Kongiwe Environmental (Pty) Ltd

4.9.6 Resource Class and River Health

According to the Classes and Resource Quality Objectives of Water Resources for Catchments of the Middle Vaal (DWS, 2016), the present ecological state (PES) of quaternary catchment C42K is considered as Class C (moderately modified). The PES of quaternary catchment C42K is not indicated in the proposed Reserve (DWS, 2018). The recommended ecological category (REC) is considered as Class C for quaternary catchment C42K according to the Classes and Resource Quality Objectives of Water Resources for Catchments of the Middle Vaal (DWS, 2016), while the REC is not indicated in the proposed Reserve (DWS, 2018). This is discussed in Section 4.5.

4.9.7 Reserve

The Classes and Resource Quality Objectives of Water Resources for the Catchments of the Middle Vaal inform the surface water reserves for the area and the limits are indicated in Table 4-6.

4.9.8 Biomonitoring and Toxicity Testing

Routine biomonitoring and toxicity testing are currently not undertaken at the Joel Operation.

4.9.9 Surface Water Survey

Surface water use in the catchments within which the Joel Operation include:

- Industrial (mining);
- Domestic (potable water via the dams after treatment by Vaal Central Water Board); and
- Agricultural (e.g. livestock watering and irrigation).

4.10 Groundwater

Refer to Specialist Study: Appendix F – Groundwater Flow and Mass Transport Model

Joel Operation falls under the Witwatersrand Supergroup. The Witwatersrand Basin is a thick sequence of shale, quartzite and conglomerate. The development and preservation of the Witwatersrand Basin is structurally controlled. The structural patterns control the regional flow of groundwater. It is important to understand which structural features act as conduits, and which act as groundwater flow barriers. Dykes and sills of at least four different ages have intruded the Witwatersrand strata. The intrusion of the dykes has often taken place along fault planes. The oldest dykes are usually diabase, representing feeder dykes to the overlying Ventersdorp lavas. There are intrusions of pyroxenite, gabbro and dolerite probably of Bushveld age. A third group belongs to the basic or alkaline dyke swarm related to the Pilansberg alkaline complex. Finally, the youngest intrusions are of Karoo dolerite.

4.10.1 Aquifer

According to Golder (2008), two main aquifers exist in the area; these are (a) a shallow aquifer associated within the weathered and fractured zone of the Karoo lithologies, and (b) a deeper aquifer which is developed in the fractured and faulted Ventersdorp and Witwatersrand rocks. Deep fractured aquifer: The deep aquifer occurs in the fractured rocks of the Witwatersrand and Ventersdorp Supergroups which are located hundreds of meters below surface. This aquifer is confined by the thick sequence of overburden. The yield of the deep aquifer is highly dependent upon geological structures, with flow occurring predominantly along faults, fractures and intrusive contact zones.

Pumping from the deep aquifer system was initiated across the Free State Gold Fields in 1952 in order to dewater working areas. Rest water levels have declined by hundreds of meters since dewatering was initiated. However,

© 2025 Kongiwe Environmental (Pty) Ltd

no corresponding drop in water levels within the shallow aquifer has been noted as a response to dewatering, providing further evidence that the shallow and deep aquifer systems are not hydraulically connected. The extreme depth of the aquifer and the low permeability of the confining strata ensure that this aquifer receives minimal recharge, which has contributed to the progressive deterioration of water quality within this aquifer (Harmony Saaiplaas EMPR, 2002). The origin of groundwater within the deep aquifer is less well understood but is thought to be connate (original formation water) or extremely old (fossil) and is usually concentrated on geological structures such as fault zones or igneous intrusions (e.g. dykes).

The depth of the fossil aquifer associated with the Witwatersrand rocks was approximated with a finite element simulation program by the WRC to be 300m below surface. Mining prospecting boreholes indicated this level to be between 170-270 m.

The original occurrence of artesian water intersections and the subsequent self-evident development of two distinctly separate water tables within the Welkom Goldfields have to be based on the existence of a persistent impervious layer. Considering the fact that the early artesian intersections were always associated with pre-Karoo rocks and the fact that the layers of the Ecca Group represent the only persistent stratigraphic zone in the required position, it has to be accepted that this group represents the impervious layer responsible for the development of artesian conditions. It need hardly be emphasized that the relatively undisturbed, impervious and incompetent nature of the shales of the Ecca Group result in this zone being an ideal barrier between the two water systems. The only possible alternative would be the Ventersdorp Supergroup, but this possibility may be eliminated without reservation on the grounds that many artesian intersections occurred within this zone and that layers of this group are, by far, too limited in their aerial distribution to explain the observed facts (Bekker, 1986).

4.10.2 Hydraulic Properties

From the limited available aquifer tests conducted across the study area in the boreholes drilled it is evident that hydraulic conductivity values (transmissivity) may vary by orders of magnitude both spatially and with depth. On average, the rock becomes solid below 80m from surface. The geological setting is complex as a result of the intrusion of diabase into the older rocks and faulting which may or may not be enhancing development of higher hydraulic conductivity zones.

The major hydrostratigraphic units of probably different hydraulic properties that exist within the study area are:

- Karoo Sequence (Ecca Group) sandstone, siltstone and shale.
- Post-Karoo dolerite dykes and diabase dykes.

Each of the above units required to be sub-divided into an upper weathered zone and a lower fractured zone.

4.10.3 Monitoring Borehole Positions

The monitoring boreholes are shown in Figure 4-10 and Table 4-17. Information available at these boreholes are water levels and water quality measured at various time intervals. No drilling information depicting the geology encountered or any other hydrogeological testing data are available at these sites. Table 4-17 shows the borehole coordinates and the surface elevations for the 19 monitoring boreholes at Joel Operation. Table 4-18 shows the monitoring boreholes where water level monitoring records could be obtained – the most recent water level available for that location is reported.

© 2025 Kongiwe Environmental (Pty) Ltd

Table 4-17 Joel Operation Monitoring Borehole Coordinates

X Co-ordinate (m) Cape LO27	- Y Co-ordinate (m) Cape LO27	Borehole Identification Number	Z – Elevation (mamsl)
-17354.80	-3128094.80	EP1	1388.34
-16766.90	-3129226.00	EP2	1389.40
-16460.80	-3129112.80	EP3	1385.40
-15726.64	-3127795.87	J1	1365.13
-16496.39	-3129938.08	J5	1393.04
-16541.18	-3130415.64	J15	1397.70
-16105.38	-3129052.15	J7	1379.75
-16145.56	-3128995.74	J8	1378.79
-15634.03	-3127292.21	J11	1354.55
-14294.65	-3128175.30	J12	1374.55
-13634.88	-3129716.79	J13	1389.97
-15810.97	-3127368.00	J9	1358.99
-18817.24	-3127553.47	J6	1362.97
-15955.37	-3127404.73	J3	1360.97
-17799.33	-3129299.22	KLM1	1406.30
-16550.51	-3127445.59	KLM2	1371.58
-15926.97	-3127403.20	KLM3	1360.68
-15690.02	-3128636.36	KLM4	1377.44
-17251.30	-3124960.30	WD1	1341.08

Table 4-18 Water Levels for Monitoring Boreholes

X Co-ordinate (m) Cape LO27	Y Co-ordinate (m) Cape LO27	Borehole Identification Number	Z Elevation	Water Level (mamsl)	Water Level (mbgl)
-15726.64	-3127795.87	J1	1365.13	1359.03	6.10
-15634.03	-3127292.21	J11	1354.55	1344.85	9.70
-15531.75	-3127112.25	J2	1352.87	1346.57	6.30
-16496.39	-3129938.08	J5	1393.04	1385.15	7.89
-17799.33	-3129299.22	KLM1	1406.30	1397.70	8.60
-16550.51	-3127445.59	KLM2	1371.58	1370.78	0.80
-15926.97	-3127403.20	KLM3	1360.68	1357.68	3.00
-15690.02	-3128636.36	KLM4	1377.44	1369.34	8.10

© 2025 Kongiwe Environmental (Pty) Ltd

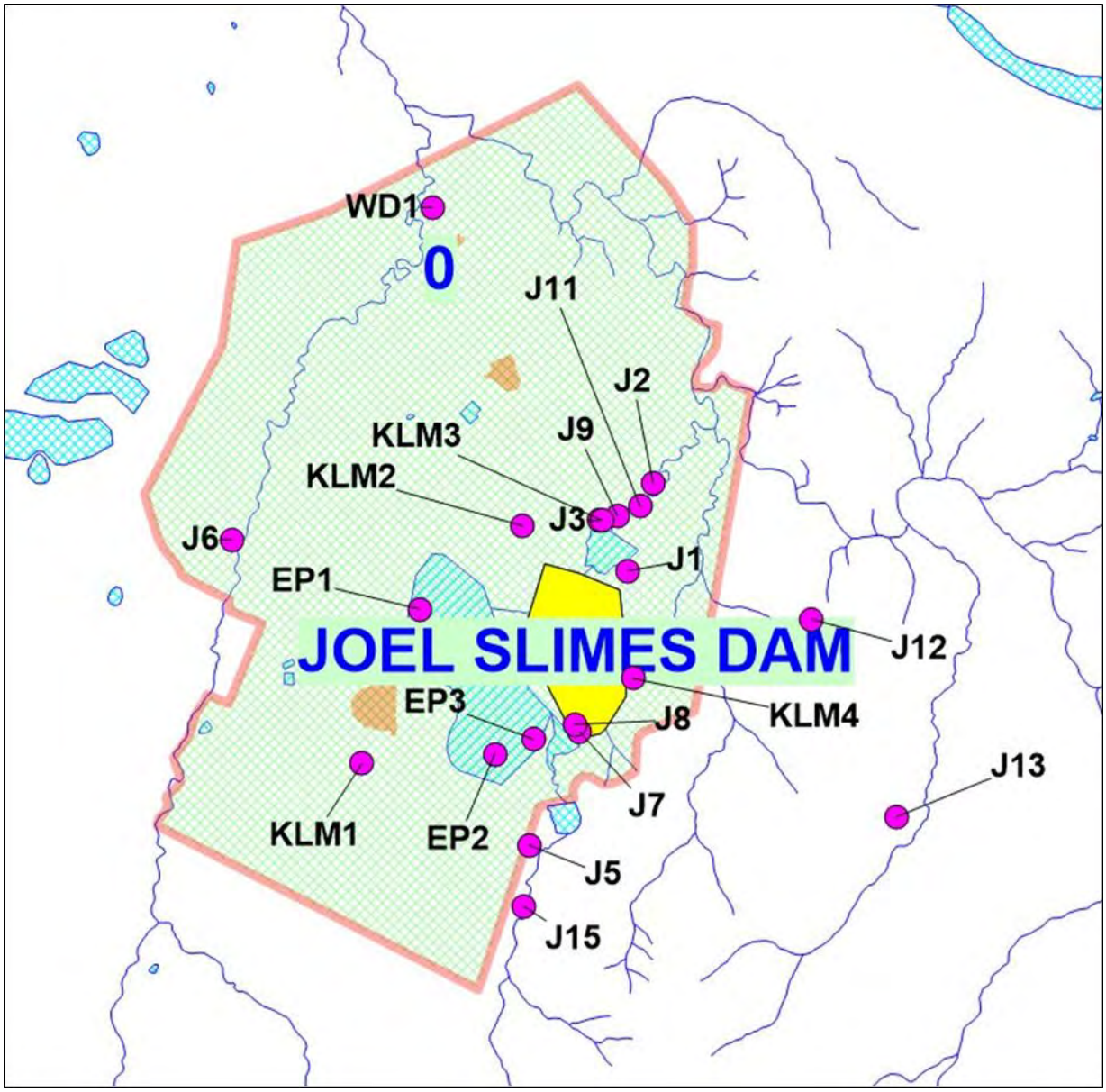


Figure 4-10 Monitoring Boreholes at Joel Operation

4.10.4 Groundwater Levels vs. Topography

Water levels across the Harmony Operation mimic the surface topography to a considerable extent. This can be observed in Figure 4-11 where the water level elevations measured in the observation boreholes for Harmony Welkom are correlated with the corresponding surface elevations. A very strong correlation coefficient of 98.5% is obtained between these two parameters.

© 2025 Kongiwe Environmental (Pty) Ltd

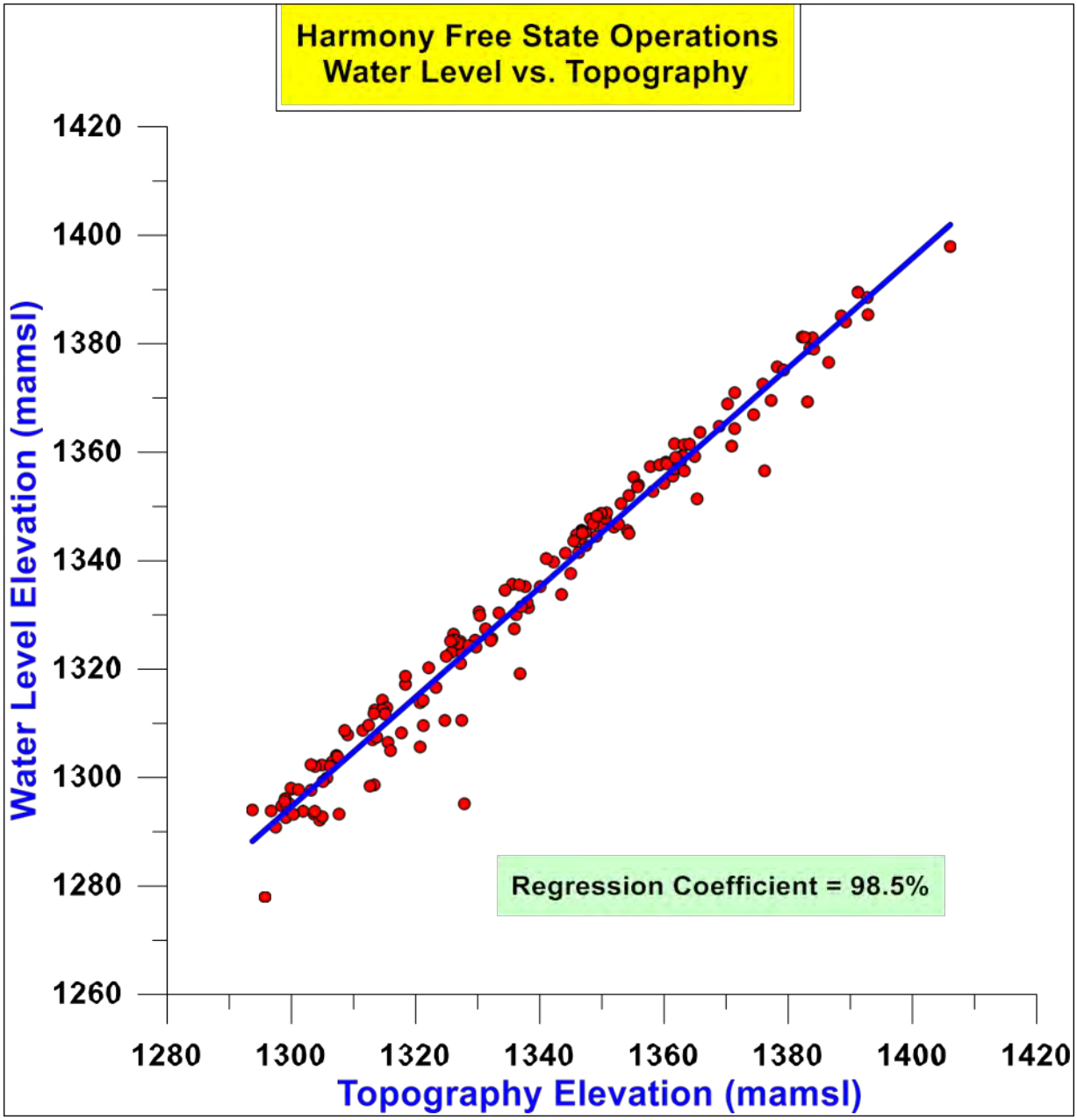


Figure 4-11 Welkom Harmony - Water Level vs Topography

The depth to the water table across the study area varies between zero and 33 metres below ground level. Figure 4-12 shows the frequency histogram depicting the depth to the groundwater level below surface. From the frequency histogram, it is evident that the data is log-normally distributed. Average depth to water level below surface is 5.28m. The median value is 4.00m. From the graph, it is further evident that the highest frequency is in the interval 0-4 metres below ground surface.

© 2025 Kongiwe Environmental (Pty) Ltd

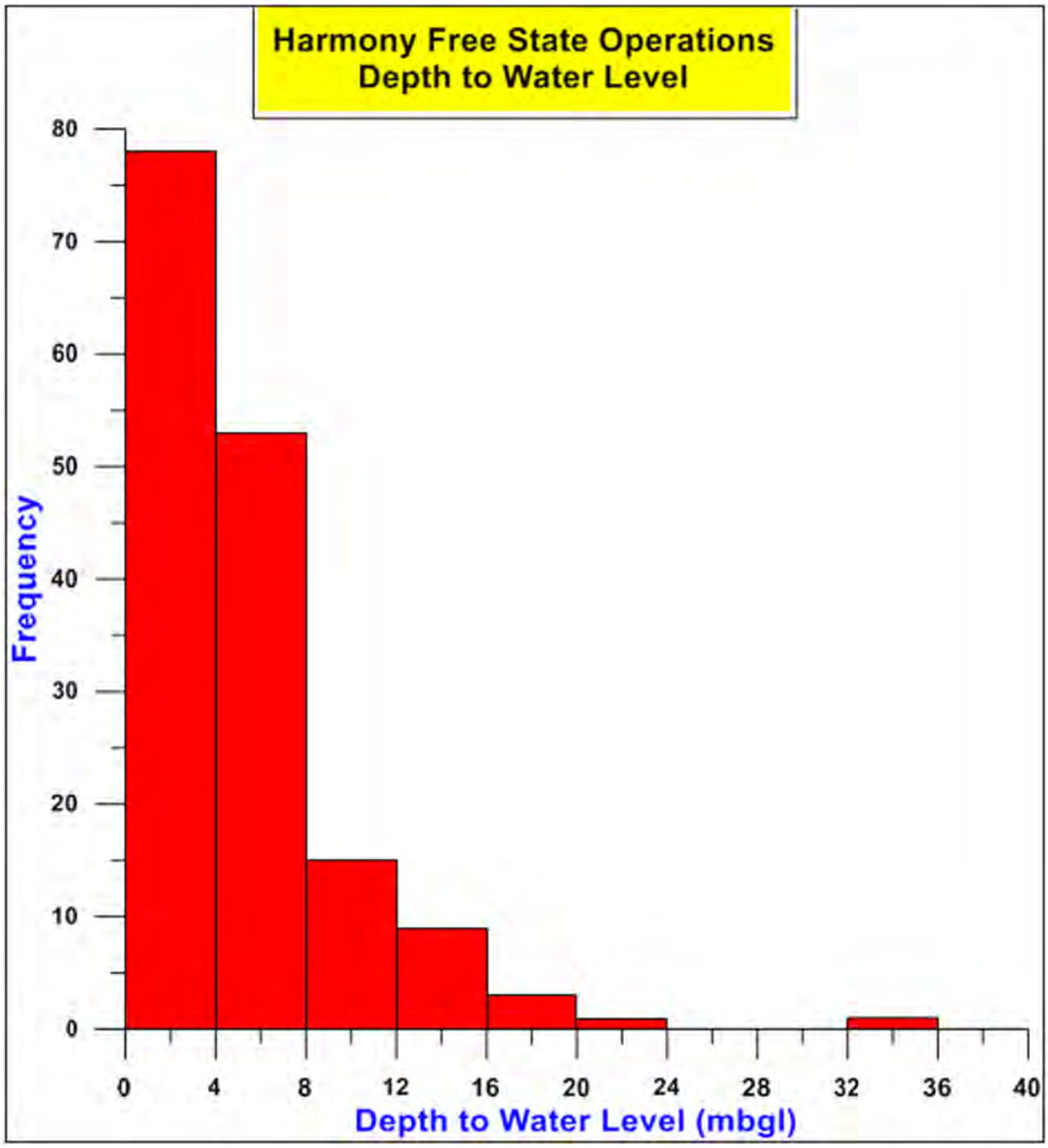


Figure 4-12 Welkom Harmony- Depth to Water Level Frequency Distribution

4.10.5 Groundwater Level Contours

Groundwater level elevation contours were prepared from groundwater level monitoring data of the data sets available. These contours are depicted in Figure 4-13. According to the groundwater level elevations groundwater flows along the natural drainages of the various sub-catchments and flow conforms to the surface water drainage. The observed groundwater levels will be used for steady state model calibration.

© 2025 Kongiwe Environmental (Pty) Ltd

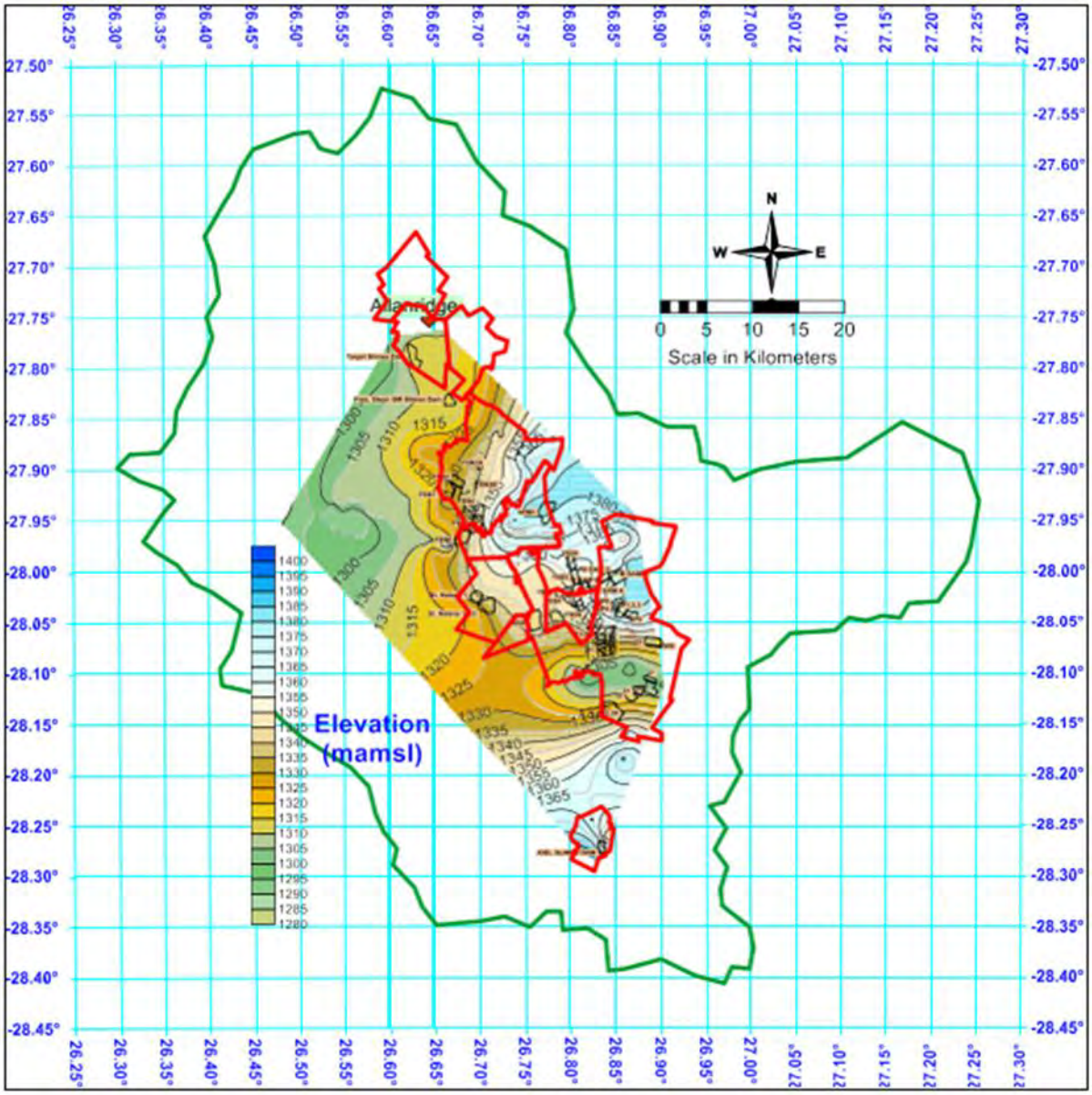


Figure 4-13 Observed Groundwater Flow Contours

4.10.6 Groundwater Flow Directions

Groundwater flow directions are indicated on Figure 4-14 by the red arrows. According to this map groundwater flow is to the northwest in the Target Operation area (along the Sand Spruit), along the Mahem Spruit and to the Dankbaar Pan in the west, to the Doring Pan in the northeast of the study area, to south towards the Sand River (north of the Sand River), to the north (south of the Sand River, and to the north along the Doring River in the south at Joel Mine. According to the contour shapes Wit Pan is also a receiving (gaining) feature in terms of groundwater movement.

© 2025 Kongiwe Environmental (Pty) Ltd

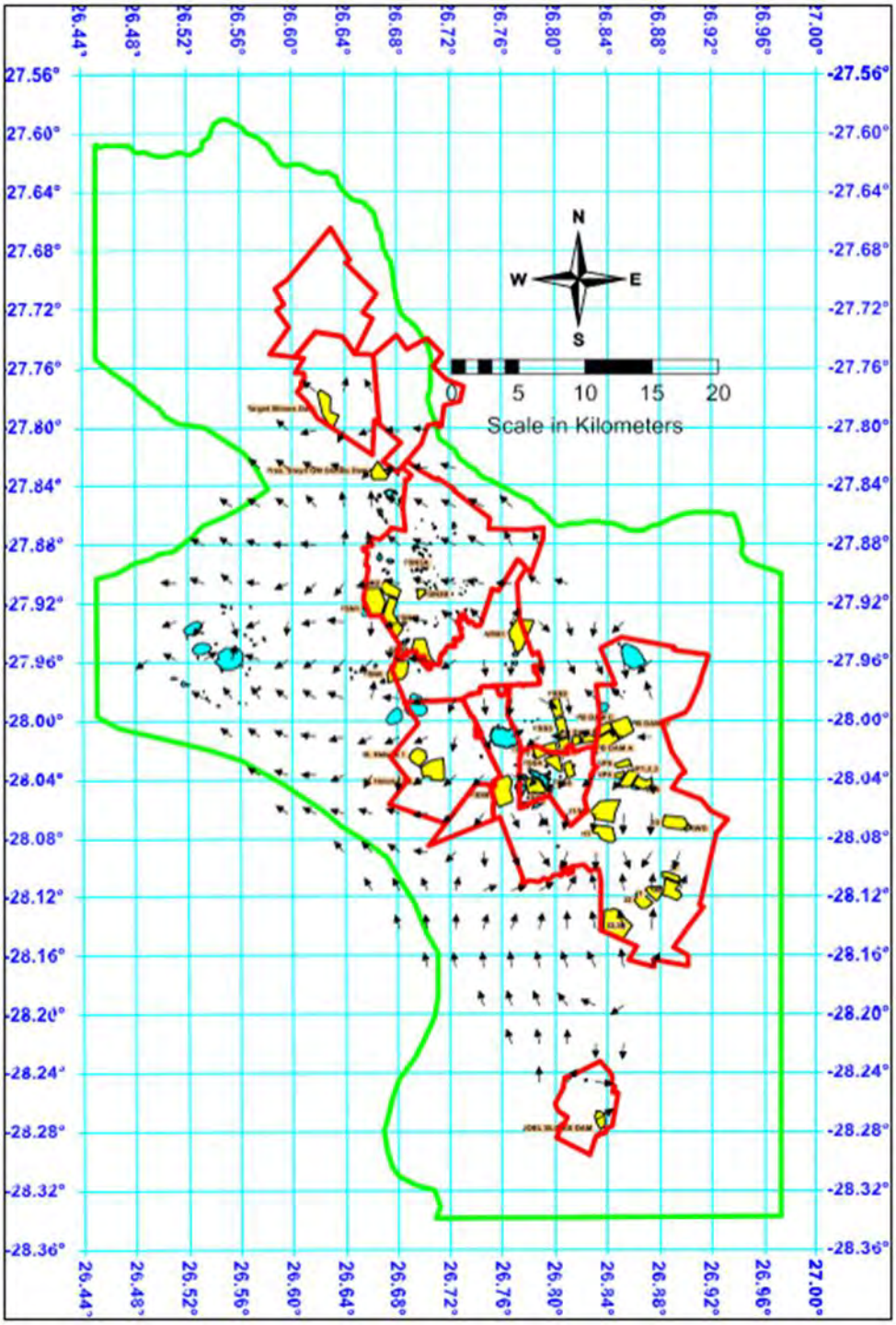


Figure 4-14 Groundwater Flow Directions Indicated by Black Arrows

4.10.7 Detailed Analysis of Contamination Impact from Source Areas

The Joel Mine Operations are situated about 20 km southwest of the town of Virginia and on a watershed between the Theron Spruit to the west and the Doring River to the east as depicted on Figure 4-15. The sources depiceted on Figure 4-15 are describe in Table 4-19. The main sources in terms of size and contamination are the Joel Evaporation Dams and the Joel Slime Dam Complex.

© 2025 Kongiwe Environmental (Pty) Ltd

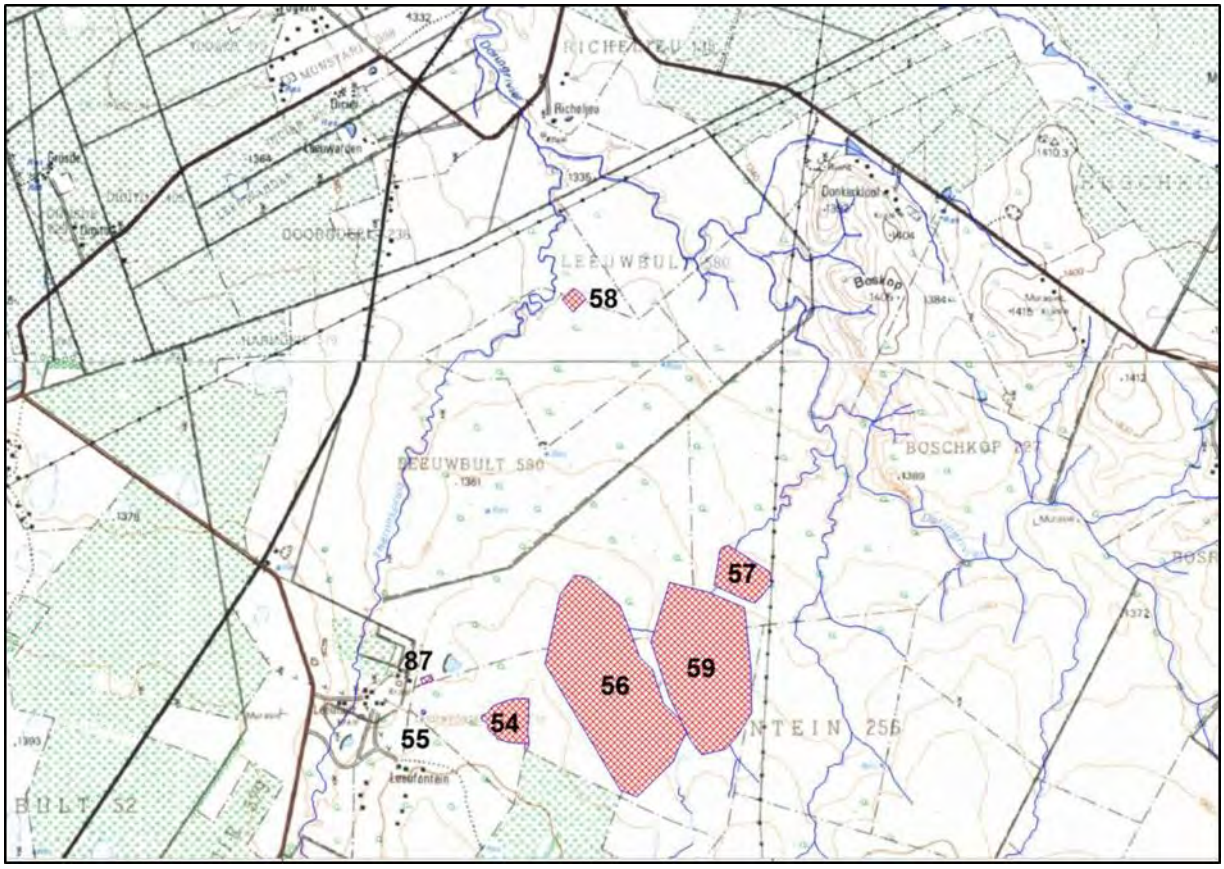


Figure 4-15 Location of the Joel Operation. Sources are indicated by the Red Cross Hatched Areas

Table 4-19 Joel Operation Source Description

No on Map	ID	Source	Purpose / Description	SEEPAGE RATE (m/d)	CONCENTRATION N (mg/l)	FEFLOW (mg/l*m/d)
54	J_G4	Joel 3 South (Taung South) Shaft Waste Rock Dump	Waste rock dump (dormant)	4.74247E-05	96	0.004553
55	J_G2	Joel 3 South Shaft TK1 Water Tank	Contains water abstracted from underground	1.00E-06	186	0.000186
56	J_G1	Joel Evaporation Dams	Excess water from the shafts and return water dam (emergency use only)	0.000142274	978	0.139144
57	J_G6	Joel Return Water Dam	Return Water Dam	0.000142274	1000	0.142274

© 2025 Kongiwe Environmental (Pty) Ltd

58	J_G3	Joel Sewage Plant	Sewage treatment plant	1.00E-06	46	0.000046
59	J_G5	Joel Slime Dam Complex	Tailings storage facility (dormant)	0.000142274	1942	0.276296
87	J_G7	Settler Dams	Store slurry from underground	0.000142274	1000	0.142274

4.10.7.1 Groundwater Elevation Contours and Flow Directions

The groundwater elevation contours and groundwater flow directions are depicted in Figure 4-16. The regional groundwater flow follows the regional topography which is from southeast and southwest to the north following the Theron Spruit and the Doring River. From a groundwater flow point of view, these two surface drainages will form Receptors in the Source- Pathway- Receptor (SPR) analysis.

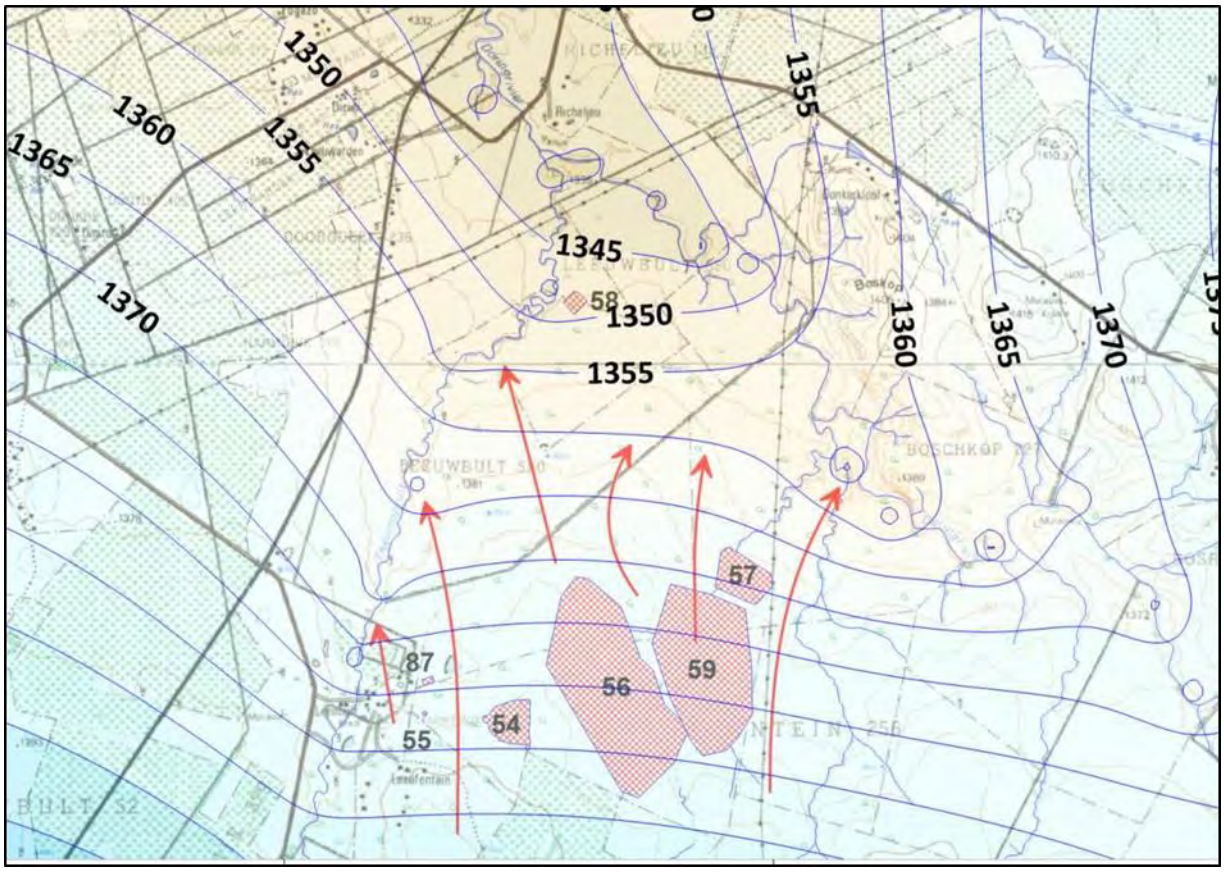


Figure 4-16 Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows.

4.10.7.2 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes

The simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes are depicted in Figure 4-17. From this figure it is evident that the sulphate migrates to the northwest

© 2025 Kongiwe Environmental (Pty) Ltd

towards Theron Spruit in the west and to the north and northeast towards the Doring River from the Joel Mine Complex.

In general, the correspondence between the simulated sulphate concentrations and the observed sulphate concentrations in the boreholes is good from a qualitative perspective. The map in general indicates that the simulated plumes overlap with areas of poorer observed water qualities. It is also evident from the map that in most cases where observed qualities seem unaffected that the model prediction agrees.

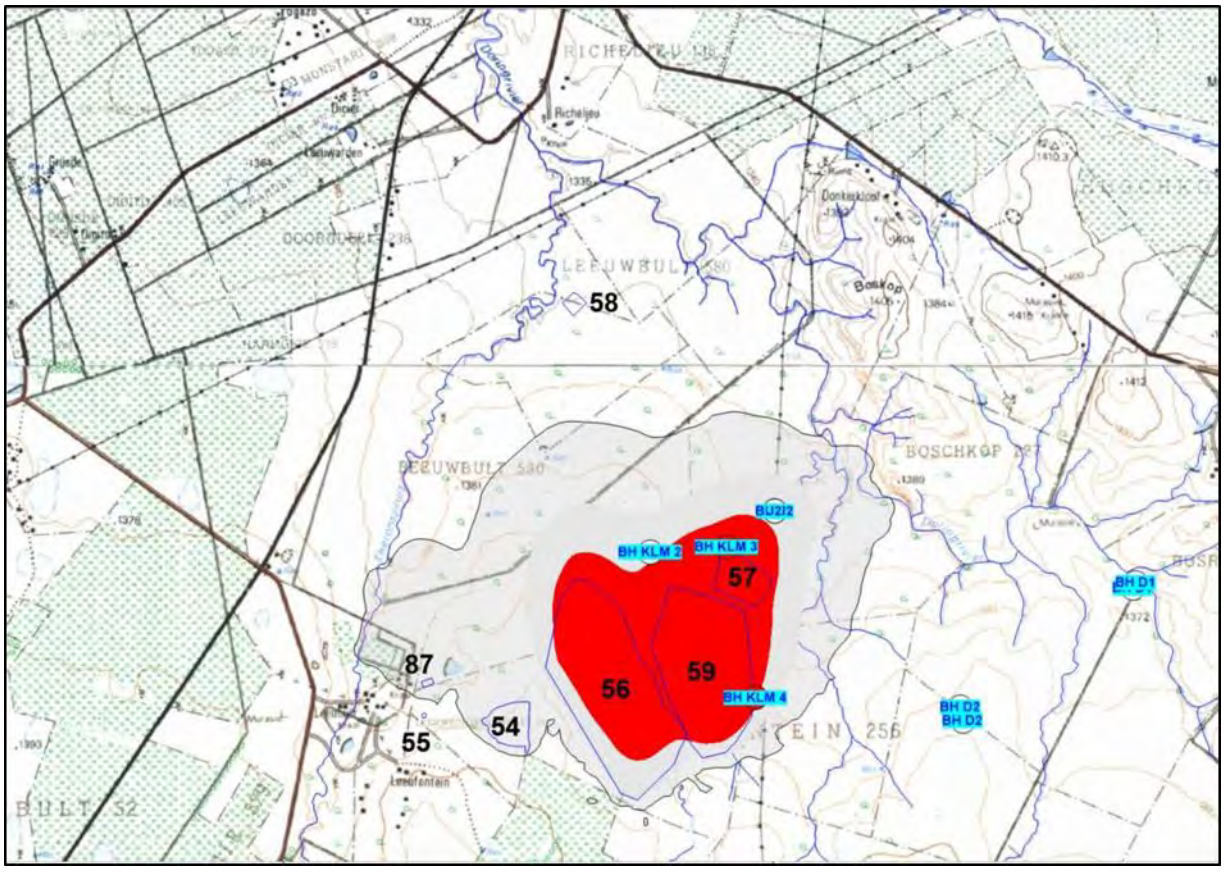


Figure 4-17 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers).

4.10.7.3 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR)

The mass loads from the sources to the groundwater pathway are depicted in Figure 4-18 and the cumulative mass loads from the sources to the groundwater pathway depicted in Figure 4-19.

The mass loads from the groundwater pathway to the receptors are depicted in Figure 4-20 and the cumulative mass loads from the groundwater pathway to the receptors depicted in Figure 4-21.

© 2025 Kongiwe Environmental (Pty) Ltd

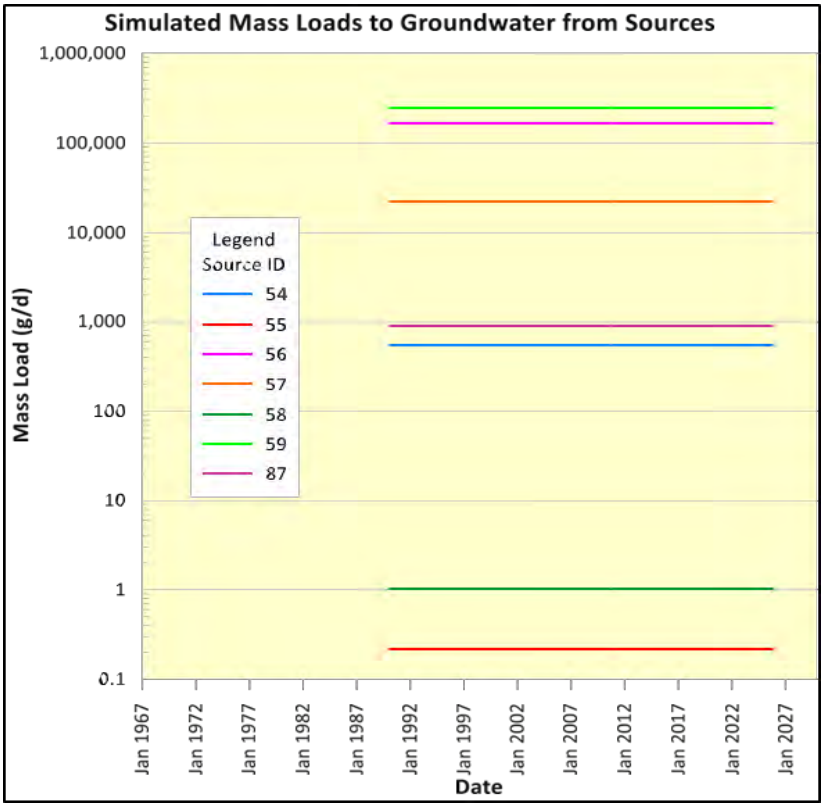


Figure 4-18 Simulated mass loads to the groundwater pathway from sources.

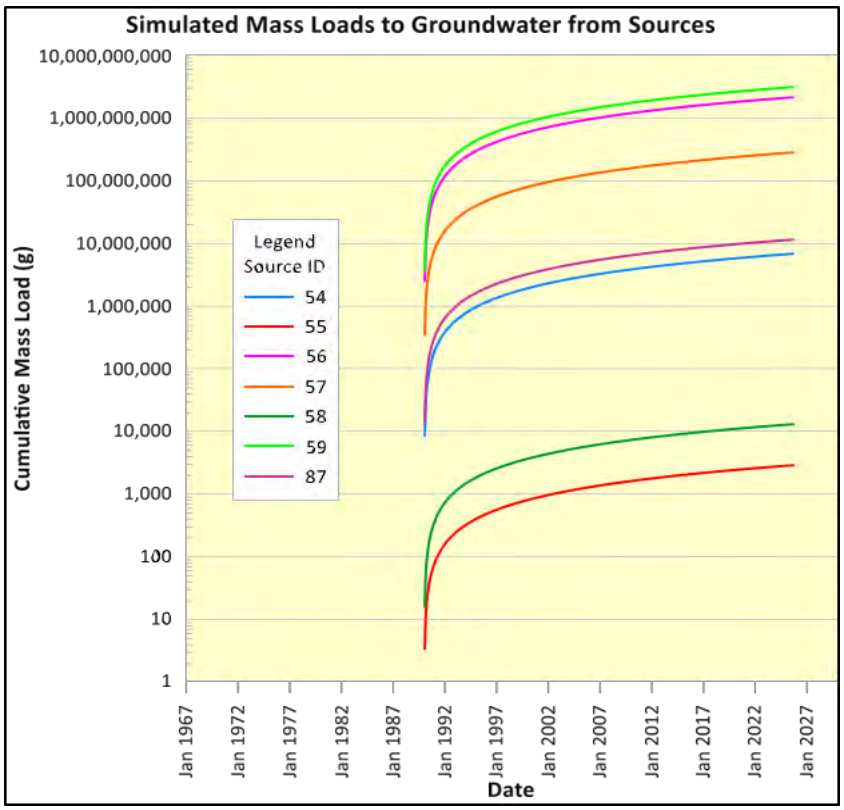


Figure 4-19 Simulated cumulative mass loads to the groundwater pathway from sources.

© 2025 Kongiwe Environmental (Pty) Ltd

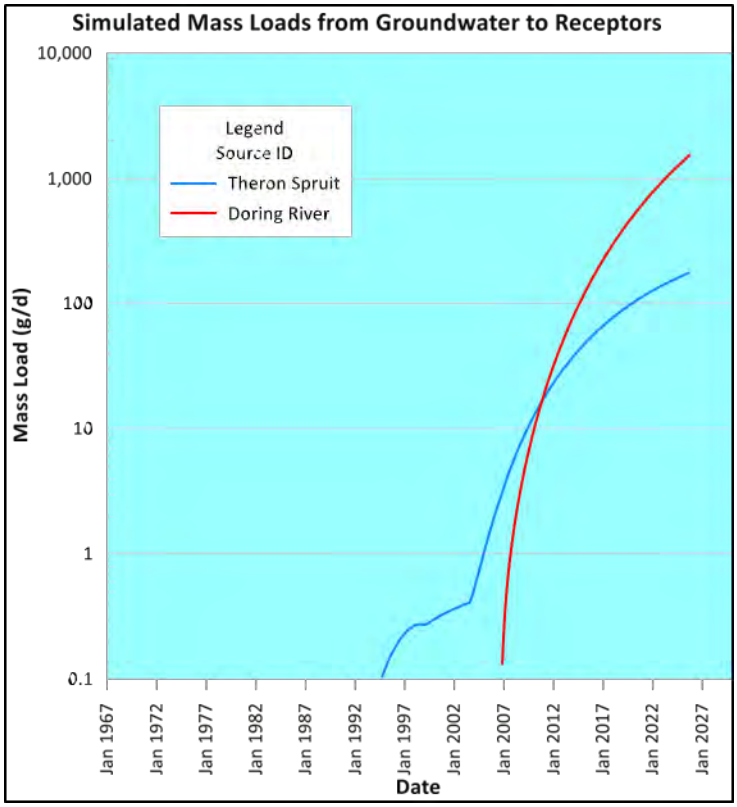


Figure 4-20 Simulated mass loads from the groundwater pathway to receptors.

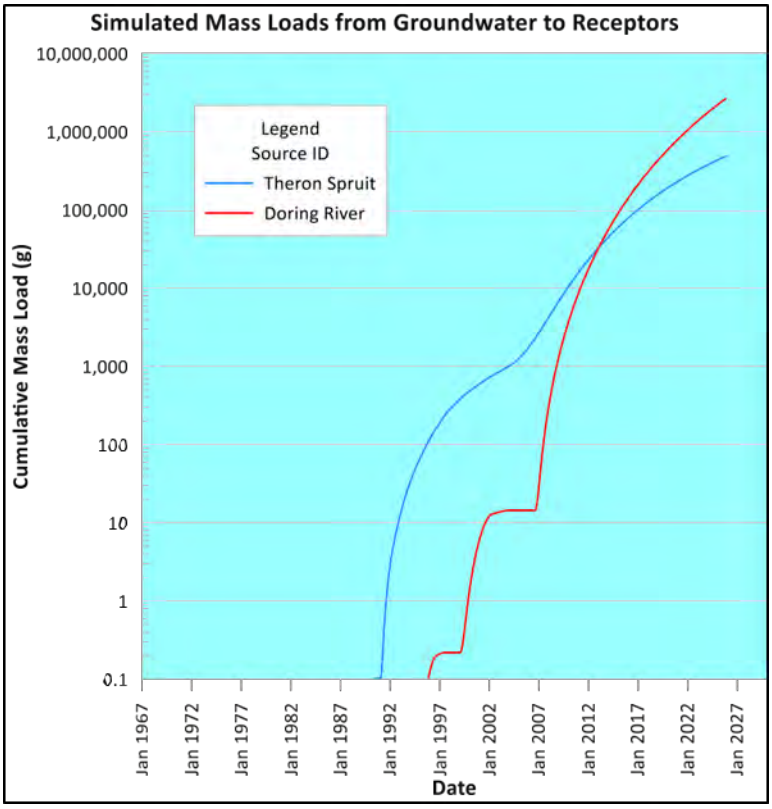


Figure 4-21 Simulated cumulative mass loads from the groundwater pathway to receptors.

© 2025 Kongiwe Environmental (Pty) Ltd

From the graphs presented the following is evident:

- Sources 56 (Joel Evaporation Dams) and 59 (Joel Slime Dam Complex) contribute by far the most mass from sources to the groundwater pathway, about 404 kg/d.
- In comparison, the remainder of the sources contributes in total only about 23 kg/d to the groundwater pathway.
- This is reflected by the simulated sulphate plume shown in Figure 4-17.
- The largest impact (although very small) from the groundwater pathway to a surface receptor is to the Doring River where about 1.50 kg/d is reporting at the end of 2025.
- The impact on the Theron Spruit is less than 0.2 kg/d.

4.11 Socio-Economic Environment

The Joel Operation is located within the Lejweleputswa District Municipality (LDM), in the Free State Province. Information in this section has been sourced from the current SLP (Harmony, 2018), previous IWWMP and the LDM Integrated Development Plan (IDP) (LDM, 2017).

The LDM has the second largest number of people living in poverty (approximately 448 163 people) in the Free State. An increase in the poverty rate of 21.3% occurred between 1996 (34.9%) and 2004 (56.1%), which mainly resulted from the decline in the mining industry and associated businesses in the area. The mining sector in the area has undergone a few restructuring processes and retrenchment of staff is still occurring, which mainly affects the mining towns of Welkom, Virginia, Odendaalsrus and Allanridge.

The average household growth of people living in the LDM has continually been lower than that of the province. In 1996, the average household growth for the LDM was 3.8%, while the growth for the province was 4.0%. In 2016, the average household growth for the LDM was 3.3%, while the growth for the province was 3.4%. It is suggested that the decrease in the average household growth over time has resulted from young adults moving out of their parents' homes and establishing homes in the form of shacks elsewhere or have successfully acquired RDP houses.

The Joel Operation provides employment to approximately 1 967 people (1 772 being mine employees and 195 being Contractors) and approximately half of the monthly salaries of the employees are spent in the mining community before the rest is sent back to the labour-sending areas (Harmony, June 2018). An increase in the money spent in the community will be done by the procurement progression plan, via the promotion of local procurement which enables the employment of people living in the region by local businesses, adding to the disposable income of families in the community. Ongoing mine community projects within the Joel Operation include the Virginia Sports Academy and Virginia Jewellery School. New mine community projects within the Joel Operation include:

- Sechaba Lesimola Business Hive;
- Youth business corners; and
- Further local economic development support (including industrial development, Small, Medium, and Micro Enterprise (SMME) development and agriculture).

© 2025 Kongiwe Environmental (Pty) Ltd

5. Analysis and Characterisation of Activity

5.1 Site Delineation for Characterisation

The existing mine lease area and the immediate surrounding area are considered in this IWWMP. The Mining Right area for the Joel Operation covers an area of approximately 2 161 ha in extent.

5.2 Water and Waste Management

An overview of the water and waste streams and management systems at the Joel Operation is provided in this section. Potential impacts of the Harmony Free State Operations at the Joel Operations are included in this section. Management actions regarding water and waste at the Joel Operations are detailed in Section 6.

5.2.1 Potable and Process Water

Potable and process water supplies are described in Section 2.6.1. The total water used in the production of gold includes:

- Potable water used per ton of material hoisted.
- Total water used for processing in metallurgical plants.

The water used in the metallurgical plants includes water removed from underground and potable water. Potable water is used at the shafts in the hoisting of materials.

5.3 Present Stormwater Management Measures

The existing stormwater measures at the Joel Operation are described below. It should be noted that the Joel Plant is non-operational and is strictly access controlled and was therefore not visited.

5.3.1 Existing Stormwater Measures

5.3.1.1 South Shaft

The South Shaft is mostly concrete-lined. The existing stormwater measures consist of the following:

- A lined dirty water channel that conveys overflows from the TK1 Tank to the Settler Dams. The TK1 Tank stores excess groundwater, which is reused underground. Water from the TK1 Tank is also pumped to the Evaporation Dams.
- Settler Dams which receive overflows from the TK1 Tank as well as mud/sludge pumped from the underground dams via the Silo Sump.
- A lined clean water channel which conveys clean water runoff from the shaft area towards the Theronspruit. This channel also receives overflows from the Settler Dams should they overflow.
- Unlined Stormwater Dam which receives runoff from the shaft area and overflows towards the Theronspruit.
- Dirty water is collected in trenches and diverted to sump(s) and pumped back into the process water circuit for reuse or evaporation.
- Clean water channels divert storm water to the storm water dam or Theronspruit.

5.3.1.2 North Shaft

The North Shaft consists of the following stormwater measures:

- A clean water channel to prevent upslope runoff from flowing towards the shaft.
- Lined Wash Bay Sumps receive runoff from the shaft area.

© 2025 Kongiwe Environmental (Pty) Ltd

- A lined dirty water channel conveys runoff from the shaft area to the Wash Bay Sumps.

5.3.1.3 Other Areas

The existing stormwater measures at other areas at the Joel Operation include:

- Berms around the North and South WRDs to contain runoff from those facilities.
- Clean water channel that diverts upslope runoff around the TSF Complex and Evaporation Dams.
- Toe paddocks and solution trench around the TSF Complex, that captures and conveys runoff and seepage to the RWD.
- Evaporation Dams that receive and evaporate excess underground water.

5.3.2 Clean and Dirty Areas

The dirty areas at the Joel Operation include the TSF Complex, WRDs, RWD and sections of the shafts. Dirty areas should be contained to ensure that they do not flow or seep into clean areas. The remaining areas should be managed as clean areas, which should not be contaminated by dirty areas, or flow into dirty areas.

5.3.3 Proposed Stormwater Measures and Recommendations

The following are proposed stormwater measures and recommendations for the Joel Operations:

- A berm is proposed on the southern boundary of the South Shaft, to ensure that no upslope external clean water flows into the shaft area;
- All sump pumps should be installed with automatic water level sensors to ensure that the sumps do not overflow;
- For the shaft areas to be operated as clean areas, it is of outmost importance that all hydrocarbon and hazardous areas are lined and contained, and that they report to dirty water containment facilities. Hydrocarbon spills as well as any other hazardous spills at the shafts, must be cleaned up immediately for these areas to be operated as clean areas. This may require more frequent inspections and for the drivers of machinery and vehicles to be equipped with spill kits;
- Sump S1 should be monitored during high rainfall events. If it is found that this sump overflows on a regular basis, then the size of the sump should be increased. Alternatively, S3 should be fitted with a big enough pump that ensures that the sump does not overflow. The same is proposed for S2;
- Where the berms surrounding the WRDs have been opened for road access, it is proposed that ramps are built across the roads so that runoff is contained within the footprint area of the WRDs;
- The water levels of the Evaporation Dams, RWD, Settler Dams and Stormwater Dam should be monitored and recorded; and
- The clean water channel/diversion CC2 should be extended so that it does not discharge towards the South WRD.

5.4 Water and Salt Balance

5.4.1 Water Balance

A water balance incorporating the Section 21 (a), (b), (f), (g), (j), (c) & (i) water uses requiring authorisation has been developed for the Joel Operation and is presented below in Figure 5-1. Refer to Appendix E for the operation's Quantity Report for September 2024 to February 2025.

© 2025 Kongiwe Environmental (Pty) Ltd

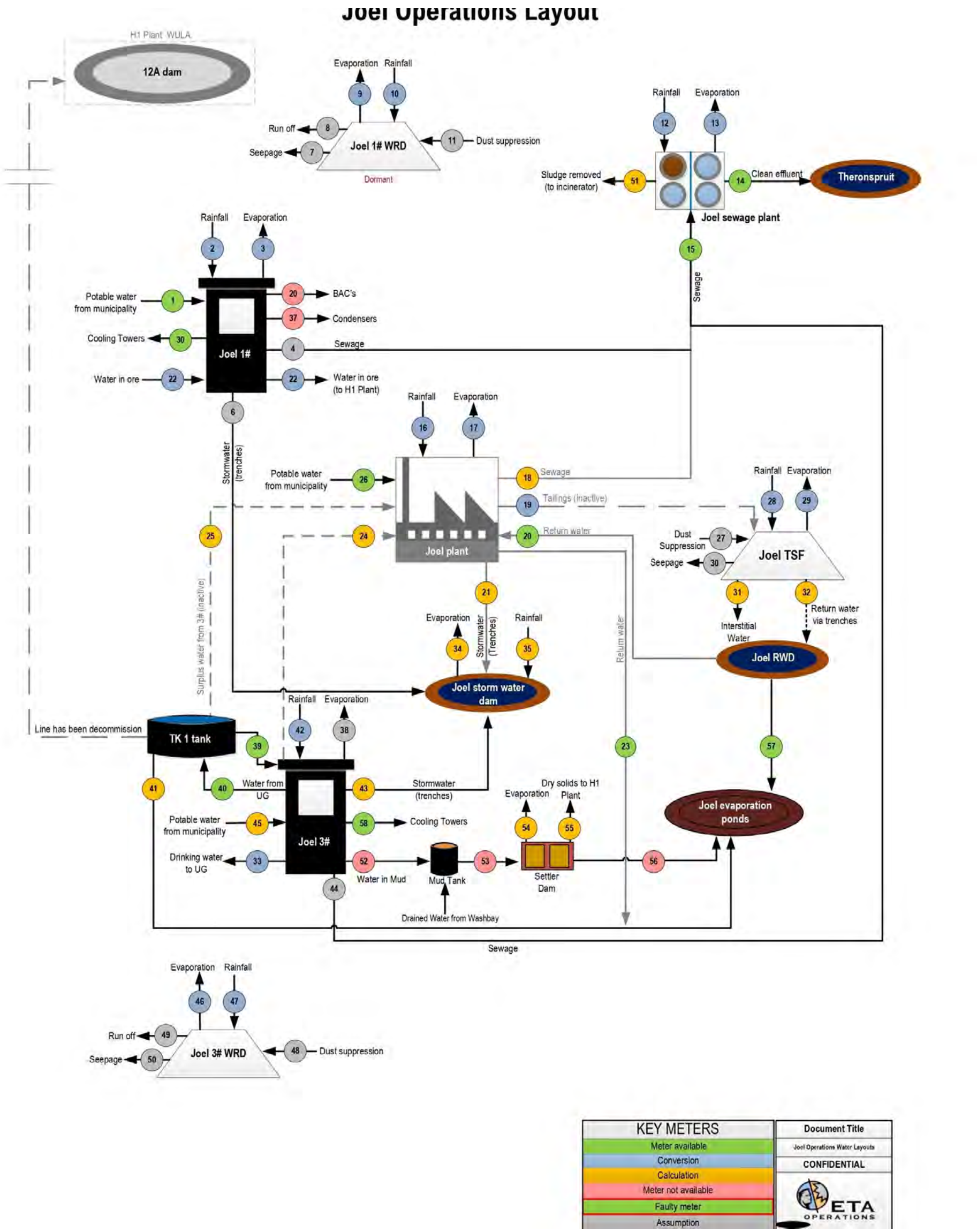


Figure 5-1: Joel Water Balance (2025)

© 2025 Kongiwe Environmental (Pty) Ltd

5.4.2 Salt Balance

A salt balance has not been developed for the Joel Operation.

5.5 Waste

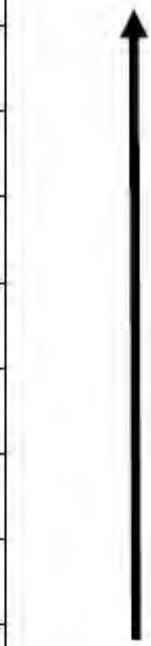
5.5.1 Non-Mine Residue

Waste minimisation is a component of Harmony's Waste Management Strategy, and the goal is to reduce quantities of waste disposed of to landfill by recycling as much as possible at all operations. The strategy's purpose is to establish and implement a waste management procedure that is applicable to the employees and companies involved in the sorting, loading, transporting, recycling and disposing of waste products generated from the various mining-related activities, in compliance with the environmental requirements and legislations.

The procedures to be followed to ensure the effective management of waste at the various operations are as follows:

- Implementation of waste management practices as per the waste management hierarchy presented in Table 5-1 which includes:
  - The prevention of the generation of waste and the contact of waste with water.
  - The reduction in the amount of waste generated.
  - The re-use and recycling of waste as much as possible.
  - The disposal of waste on appropriate and authorised facilities if it cannot be re-used or recycled.
- Characterisation of waste to determine the potential risk posed and protection required.
- Implementation of a waste information system.

Table 5-1: The Waste Management Hierarchy (Jones & Wagener, 2017)

The Waste Hierarchy		
Cleaner production	Prevention	
	Minimisation	
Recycling	Re-use	
	Recovery	
	Composting	
Treatment	Physical	
	Chemical	
	Destruction	
Disposal	Landfill	

© 2025 Kongiwe Environmental (Pty) Ltd

5.5.2 WRDs

Joel 1 North (Taung North) Shaft and Joel 3 South (Taung South) Shaft are domant.

5.5.3 TSFs

No tailings are currently being disposed at Joel Slime Dam Complex because the tailings storage facility is dormant.

5.6 Operational Management

Procedures are in place at the Joel Operation, to deal with potential polluting incidents. The incident classification criteria is presented in Table 5-2.

Table 5-2: Harmony Incident Classification Criteria (Harmony Risk Matrix - October 2019)

Severity Level	Mitigation Costs	Environmental Impact	Reputational Impact	Legal Impact
5	>R10 000 000	Irreversible damage on habitat or ecosystem	International condemnation	Potential director liability
4	<R10 000 000	Significant impact on habitat or ecosystem	National and international concern – NGO involvement	Very significant fines or prosecutions
3	<R5 000 000	Longer-term impacts & ecosystem compromised	Adverse media attention – locally/nationally	Breach of legislation and likely consequences from regulator
2	<R1 000 000	Moderate short-term effects but not affecting the eco-system function	Unresolved local complaints and possible local media attention	Minor breach of legislation
1	<R500 000	Localised affected area of low impact	Local complaints	No major breaches of legislation

Incidents classified as Level 3 and above are reported to DWS within 24 hours, initially via telephone, followed by a formal email or letter within five days of occurrence. The notifications sent to DWS contains the following information:

- Date and time of the incident.
- Description of the incident.
- Source of pollution.
- Risks/impact to safety, health, property or environment resulting from the incident.
- Remedial action taken or to be taken by the person in control, to remedy the effects of the incident and to prevent similar incidents in the future.

Formal incident investigations are undertaken by the relevant manager and the actions based on the investigations are uploaded to the business unit's Action Management System. A follow up action plan is submitted to DWS within 14 days of the incident occurring, which indicates the following:

- Measures taken to correct the impact of the incident.
- Measures taken to correct further impacts from the incident.
- Measures taken to prevent the reoccurrence of a similar incident.

© 2025 Kongiwe Environmental (Pty) Ltd

An environmental incident that has been classified as Level 1 or 2 is reported internally. A formal incident investigation is not undertaken for these incidents, unless the same incident has repeatedly occurred three or more times within three months.

5.6.1 Organisational Structure

The persons that will be responsible for the implementation of the WUL, once issued, and the Action Plan in Section 6, are presented in Table 2-4.

5.6.2 Resources and Compliance

The environmental management resources and systems at the Joel Operation include:

- Infrastructure and equipment e.g. pollution control dams, oil traps etc.
- An Environmental Management System (EMS).
- Personnel including environmental officers, site engineers, and appointed external contractors and consultants.
- The inclusion of environmental training for all new staff.
- The promotion of environmental awareness amongst employees and contractors.
- Annual environmental auditing and reporting.
- Registers including an incident register.
- Maintenance of a complaints register, clearly stating actions taken on specified dates.

The Environmental Officers will be supported by a Regional Environmental Manager and Joel's Management in the implementation of the WUL once issued.

5.6.3 Education and Training

The environmental training and awareness process applicable to the EMS incorporates the following:

- The importance of complying with the Environmental Policy and Procedures.
- The requirements of the EMS.
- Significant environmental aspects and the associates actual or potential impacts, and the benefits of improved environmental performance.
- The roles and responsibilities in achieving compliance with the requirements of the EMS.
- The potential consequences from not following specific procedures.

Newly appointed employees receive job and business unit specific induction and training based on the Harmony human resources and training processes. Competence, training and awareness are addressed through the induction, awareness, capability and competency training and assessments.

5.6.4 Internal and External Communication

5.6.4.1 Internal Communication

Water targets are reported on a monthly basis by the Environmental Management Department. The results from the monitoring and comparison of actual water use to the targets are included in monthly water reports, which are distributed to all the responsible environmental personnel.

Annual surface and groundwater monitoring reports are compiled for all business units to assess their impacts on the natural water resources. The monitoring reports are communicated to the business units by the Environmental Management Department.

Environmental improvements, monthly inspection findings and incidents are included in monthly environmental management reports, which are distributed to all responsible environmental personnel. The internal communication process for environmental issues is presented in Table 5-3.

© 2025 Kongiwe Environmental (Pty) Ltd

5.6.4.2 External Communication

The reporting of incidents that have the potential to cause or have caused water pollution or pollution to the environment, health risks are undertaken. Records of all incidents and system malfunctions which may result in the pollution of the water resources are reported to DWS. The incidents are recorded by the individual business units and a summary report of all incidents is compiled and submitted to the Environmental Management Department on a monthly basis.

The external communication process for environmental issues is presented in Table 5-4. The environmental complaints process is presented in Table 5-5.

Table 5-3: Internal Communication Procedure

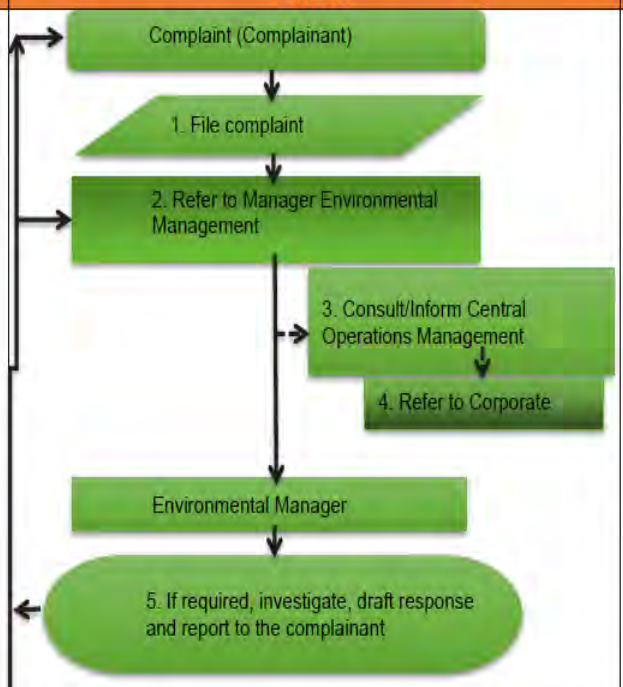
	Internal Communication Process	Notes	Responsibility/Who	When
Internal Communication	**Internal Communication** 1. Significant environmental issue (s) 2. Review issue - Environmental Management 3. If required (if significant), investigate and report to affected personnel	1. Significant environmental issues are communicated through: • Quarterly environmental topics/reports (environmental awareness, on notice boards) • Environmental Policy/EMS Procedures, Aspects • Legislation Notification or Changes • Roles and Responsibilities, Key Performance Indicators • Safety, Health and Environment Meetings • Management Meetings • Contractual obligations with interested parties e.g. contractors etc. 2. Review issue 3. If significant, investigate/report back to the affected personnel (e.g. via e-mail, section meetings)	1. Environmental Management 2. Environmental Management 3. Environmental Management	As and when required

Table 5-4: External Communication Procedure

	External Communication Process	Notes	Responsibility/Who	When
External Communication	**External Communication (excludes complaints)** 1. Receive communication 2. Refer communication to EMD 3. File communication 4. Refer / Assign responsibility 5. Arrangement / Assess / Investigate and compile report 6. Respond to the interested party	1. Received communication on e.g. needs, expectations, etc. from interested parties e.g. Government Departments, Non-Governmental Organisations, etc. at e.g. Meetings, Forums, Community Events, EIA/ EMPr Projects, etc. 2. Refer to Environmental Management 3. File communication 4. Refer/assign responsibility to relevant Environmental Manager in consultation with Senior Management 5. Investigate and determine opportunities for improvement, if required 6. Respond and/or report to Interested Party in one of the following methods: • Compile Letter or Report • Approve Letter or Report • Distribute letter/ report and or follow up in a forum to interested Party (where required).	1. Environmental Management 2. Environmental Management 3. Environmental Management 4. Environmental Management 5. Environmental Management/Central Operations Mancom 6. Environmental Management	As and when required

© 2025 Kongiwe Environmental (Pty) Ltd

Table 5-5: Environmental Complaints Process

Process	Notes	Responsibility/Who	When
	Receive complaint from Interested Parties; Refer complaint to Environmental Management Department (EMD) and Stakeholder Engagement Department 1. File compliant 2. Refer to Environmental Management 3. Consult Central Operations Mincom, if required 4. If required, consult and inform the Corporate Environmental Department 5. Address complaint: • Investigate • Draft and approve response • Report back to complainant • Record risk/ opportunities to improve the EMS and update the EMS appropriately, if needed.	Any person within Central Operations 1. Operations Management 2. Document and Records Controller 3. Environmental Management 4. Environmental Management/ Central Operations Mancom; Corporate 5. Environmental Management	As and when required

5.6.5 Awareness Raising

Environmental Awareness Plans have been developed by Harmony and have been incorporated in the ISO 14001 EMS for each business unit, ensuring that all employees, contractors and any other people offering services or doing work on behalf of the company are environmentally aware. The plans inform people of any environmental risks that may result while conducting their work and the process involved to deal with the risks in order to prevent pollution or the degradation of the environment.

Environmental awareness is communicated through the following:

- Posters;
- Campaigns;
- Briefs;
- Environmental topics;
- Programmes associated with environmental days (e.g. water week in March each year);
- Discussions at green area meetings;
- Incident reports and notifications; and
- Group SMS system or Harmony Connect Email awareness system.

5.7 Monitoring and Control

Water monitoring at the Joel Operation is undertaken by External Consultant according to BPG G3 (DWAF, 2006). The monitoring program will be reviewed annually by Harmony. The purpose of the water monitoring program at the Joel Operation is to monitor ground and surface water (surface water also comprises the process water circuit) to proactively identify and implement the actions needed to manage the water related risks of the mining operation throughout the mine's life cycle.

Surface water quality is monitored monthly & quarterly, while groundwater quality is monitored quarterly and bi-annually.

© 2025 Kongiwe Environmental (Pty) Ltd

Analysis will be undertaken at South African National Standards (SANAS) accredited laboratories. The site currently does not have any water quality standards that are applicable to them as it does not have a WUL. The site currently makes use of available standards as guidelines and will implement the official applicable standards once the WUL has been approved and the relevant applicable standards have been provided. Water quality limits that apply to the Joel Operation are presented in Table 4-15.

Should an incident occur where contamination (concentrations exceeding applicable guideline values) or reduction in community water supply is detected, Harmony will notify the Regional Director of DWS. Harmony will then:

- identify the source of the contamination/reason for loss of supply;
- identify, and if necessary, implement, measures for the prevention of this contamination (short and long term)/loss of supply; and
- determine, and if necessary, implement, any remediation measures including provision of alternative supply of water.

Solid waste monitoring in the form of recorded disposal volumes, all waste removal documents, waste manifests and certificates of safe disposal will be kept for audit purposes for the life of operation.

5.7.1 Surface Water Monitoring

5.7.1.1 Quality

The surface water quality monitoring points are presented in Table 4-14.

5.7.1.2 Quantity

Quantity monitoring includes water consumption and metering of the various water and waste streams on the mine. Where meters are not available, volumes will be calculated. The metered data is reflected in the mine water balance which is updated monthly at the individual business units for the available meter data. Excessive water use is reported to the Environmental Management Department for investigation and corrective action.

5.7.2 Biomonitoring and Toxicity Testing

Biomonitoring and toxicity testing are currently not being undertaken at the Joel Operation. It is advised that these be included. The Water Resource Baseline and Risk Assessment (2022) undertaken by The Biodiversity Company in 2022, found in Appendix B, indicates that:

> *Based on the results of the Aquatic Biomonitoring Study (May 2022), the RQOs for the applicable catchments, the following monitoring checklist was established (Table 5-6). The proposed sampling locations and the recommended methodology to be applied to each sampling location arer shown Table 5-7. It is important that the targets provided in the licence be attainable and applicable to the current circumstances on and around site. It is advised that a representative biomonitoring plan be developed and implemented in accordance with the requirements of the awarded WUL. It is advised that additional representative sampling locations be determined in this biomonitoring report*

The prescribed biomonitoring targets were a combination of both RQOs, TWQR for aquatic biota and May 2022 biomonitoring results. An analysis of sampling sites distribution, habitat availability on site, flow as well as received data was used to refine the number of sampling sites as well as which methodologies to apply at each site which is presented in Table 5-7. The monitoring program will be reviewed every two years by Harmony to assess its applicability based on mining activities still occurring. This biomonitoring plan was compiled according to different river systems:

© 2025 Kongiwe Environmental (Pty) Ltd

- Doring River and Theronspruit.

Based on the outcomes of the 2022 Water Resource Baseline and Risk Assessment, further actions are recommended:

- The biomonitoring programme is imperative to establish biological trends and monitor the impacts of the mine throughout the lifecycle of the mine which includes post closure monitoring.
- The results of the established surface water monitoring programme should be integrated into the biomonitoring programme to provide insight.
- Due to the inefficacy of fish sampling in the systems, diatoms were suggested as a better ecological indicator in many systems.
- Alien invasive vegetation assessments must be conducted in accordance with the terrestrial component of this overall application.
- Measures to improve or achieve the targets established are outlined in the risk assessment mitigation measures.

© 2025 Kongiwe Environmental (Pty) Ltd

Table 5-6: Recommended Monitoring Checklist for Joel Operation

Key Performance Indicator	Target	Location	Frequency of monitoring	Attenable Biomonitoring Target/limits
				Doring & Theronspruit
Water quality	Salt concentrations must be at levels that do not threaten the ecosystem and are suitable for users. Dissolved organic carbon concentrations must not cause the ecosystem to become unsustainable. An appropriate chemical analysis program is recommended.	Current sites used in the 2022 Water Resource Baseline and Risk Assessment.	Bi-annual (Winter & Summer Season).	pH between 7.5 – 9.2 Conductivity ≤ 700 µS/cm Dissolved Oxygen >5.00 mg/L Temperature (°C) between 5 - 30
Habitat Assessment	Instream habitat must be in a moderately modified or better condition to support the ecosystem.	Current sites used in the 2022 Water Resource Baseline and Risk Assessment	Bi-annual (Winter & Summer Season)	Instream Habitat Integrity category ≥ B (≥ 80) Riparian Habitat Integrity category of ≥ C (≥ 70)
Macroinvertebrate Assessment	SASS5 & ASPT: No significant changes from established baseline conditions.	Current sites used in the 2022 Water Resource Baseline and Risk Assessment	Bi-annual (Winter & Summer Season)	≥ C (≥ 62)
Fish Community	At least 80% of the baseline fish community must be sampled.	Current sites used in the 2022 Water Resource Baseline and Risk Assessment	Bi-annual (Winter & Summer Season)	≥ D (≥ 42) In the Doring
EcoStatus	An EcoStatus of category C must be maintained, if not improved.	Current sites used in the 2022 Water Resource Baseline and Risk Assessment	Bi-annual (Winter & Summer Season)	D (Largely Modified)

© 2025 Kongiwe Environmental (Pty) Ltd

Table 5-7: Recommended Methodology to be Applied to each Sampling Site in Future Monitoring

Site	Locality	Watercourse Type	In-situ Water Quality	Ex-situ Water Quality	SASS5	Fish	Diatoms
Doring River							
SVC 12	28°16'12.37"S 26°53'44.32"E	River	✓	✓	✓	✓	✓
ESW 71	28°17'18.64"S 26°49'55.07"E	River	✓	x	x	x	x
ESW 82	28°14'47.10"S 26°50'38.30"E	River	✓	x	✓	✓	x
ESW 65	28°14'5.45"S 26°50'53.06"E	River	✓	x	x	x	x
SVC 04	28°13'55.06"S 26°49'13.07"E	River	✓	✓	✓	✓	✓
SVC 05	28°11'17.94"S 26°47'54.00"E	River	✓	x	✓	✓	x
SVC 07	28° 8'4.65"S 26°44'10.23"E	River	✓	x	✓	✓	x
Theronspruit							
ESW 79	28°16'43.39"S 26°48'15.90"E	River	✓	x	x	x	x
ESW 80	28°15'55.00"S 26°48'30.60"E	River	✓	✓	✓	x	✓

© 2025 Kongiwe Environmental (Pty) Ltd

5.7.3 Waste Monitoring

Waste streams generated at the Joel Operation are monitored and recorded on a monthly basis.

5.7.4 Groundwater monitoring

The groundwater quality monitoring points are presented on the monitoring program is presented in Table 4-17.

5.8 Risk and Impact Assessment / Best Practice Assessment

Potential water and waste related environmental and socio-economic impacts were identified by WSP Environmental, as part of the EMPr update (EIMS, 2019). The impact assessment was based on the mining area and its immediate surrounding area.

A summary of the impacts during the operational phase of the operations is provided in The Joel Operation's impact assessment and recommended management measures are shown in *Table* 5-16.

Table 5-16 with additional impacts and risks indicated where applicable. The proposed mitigation measures are included in the table and specific action plans to give effect to the mitigation measures are provided in Section 6.

An additional risk assessment for the water resources was also provided as indicated by the Water Resource Baseline and Risk Assessment for the Joel Operation.

5.8.1 Risk Assessment Key

The methodology used in the risk matrix is per the DWS General Notice 509 of 2016 Appendix A "Risk Matrix (Based on DWS 2015 publication: Section 21 (c) and (i)Water use Risk Assessment Protocol. The scoring system used is per the Table 5-8 to Table 5-15.

5.8.1.1 Calculating the Level of Consequence

The level of consequence is calculated by combining scores relating to the level of the severity, spatial scale and duration of the impact.

Consequence = Severity + Spatial Scale + Duration

The level of severity is based on an assessment of flow regime, water quality, habitat and biota – each of which is scored according to the ratings in Table 5-8.

Severity = Average of scores for: Flow Regime + Water Quality + Habitat + Biota

Impacts for flow regime, water quality, habitat and biota are scored as a 5 when activities occur within the delineated boundary of the wetland.

Table 5-8: Severity

Insignificant / non-harmful	1
Small / potentially harmful	2
Significant / slightly harmful	3
Great/ harmful	4
Disastrous / extremely harmful and /or wetland(s) involved	5

© 2025 Kongiwe Environmental (Pty) Ltd

Where "or wetland(s) are involved" it means that the activity is located within the delineated boundary of any wetland. The score of 5 is only compulsory for the significance rating

Table 5-9 below indicates how the spatial extent of the impact is scored.

Table 5-9: Spatial Scale

Area specific (at impact site)	1
Whole site (entire surface right)	2
Regional / neighbouring areas (downstream within quaternary catchment)	3
National (impacting beyond secondary catchment or provinces)	4
Global (impacting beyond SA boundary)	5

Table 5-10 below indicates how the duration of the impact is scored.

Table 5-10: Duration

One day to one month, PES, EIS and /or REC not impacted	1
One month to one year, PES, EIS and /or REC impacted but no change in status	2
One year to 10 years, PES, EIS and /or REC impacted to a lower status but can be improved over this period through mitigation	3
Life of the activity, PES, EIS and /or REC permanently lowered	4
More than life of the organisation /facility, PES and EIS scores, a E or F	5
PES and EIS (sensitivity) must be considered.	

Table 5-11 below indicates how the the frequency of the activity is scored.

Table 5-11: Frequency of the Activity

Annually or less	1
6 monthly	2
Monthly	3
Weekly	4
Daily	5

5.8.1.2 Calculating the Likelihood of the Impact Occurring

The likelihood of the impact occurring is based on the level of frequency of the activity, the frequency of the incidence, legal status and ease of detection. Scoring of each of these components is outlined in Table 5-12 to Table 5-14.

© 2025 Kongiwe Environmental (Pty) Ltd

Likelihood=Frequence of Activity + Frequency of Incident +Legal Issues + Detection

Table 5-12 below indicates how the frequency of the incident/impact of the impact is scored.

Table 5-12: Frequency of the Incident/ Impact

Almost never / almost impossible / >20%	1
Very seldom / highly unlikely / >40%	2
Infrequent / unlikely / seldom / >60%	3
Often / regularly/ likely / possible / >80%	4
Daily / highly likely / definitely / >100%	5

Table 5-13 below indicates how to score an activity based on how it is governed by legislation. ..

Table 5-13: Legal Issues

No legislation	1
Fully covered by legislation (wetlands are legally governed)	5
Located within the regulated areas	

Table 5-14 below indicates how to score an activity based on the risk associated with how quickly/easily the risk of the activity can be observed on the resource quality, or people and property.

Table 5-14: Detection

Immediately	1
Without much effort	2
Need some effort	3
Remote and difficult to observe	4
Covered	5

5.8.1.3 Calculating the Significance Rating of an Impact

The significance of an impact is calculated by multiplying the scores calculated in relation to impact consequence and the likelihood of the impact occurring.

Impact Significance Rating = Consequence x Likelihood

An additional risk assessment for the water resources was also provided as indicated by the Water Resource Baseline and Risk Assessment for Joel Operation.

© 2025 Kongiwe Environmental (Pty) Ltd

The risk assessment was completed in accordance with the requirements of the DWS General Authorisation (GA) in terms of Section 39 of the NWA for water uses as defined in Section 21(c) or Section 21(i) (GN 509 of 2016).

The significance of the impact is calculated according to Table 5-15.

Table 5-15: Significance Ratings Matrix

Rating	Class	Management Description
1 – 55	(L) Low Risk	Acceptable as is or consider requirement for mitigation. Impact to watercourses and resource quality small and easily mitigated. Wetlands may be excluded.
56 – 169	(M) Moderate Risk	Risk and impact on watercourses are notably and require mitigation measures on a higher level, which costs more and require specialist input. Wetlands are excluded.
170 – 300	(H) High Risk	Always involves wetlands. Watercourse(s)impacts by the activity are such that they impose a long-term threat on a large scale and lowering of the Reserve.

© 2025 Kongiwe Environmental (Pty) Ltd

The Joel Operation's impact assessment and recommended management measures are shown in Table 5-16.

Table 5-16: Joel Operations Impact Assessment

Impact/risk summary	Risk rating pre-mitigation	Risk rating post mitigation	Management measure
Surface water			
Surface water quality deterioration	Moderate	Low	Compare water quality results to background levels and/or the WUL (once received). Assess the quality of water conveyed in the trenches and line with concrete if a risk is posed. Collect dirty runoff in appropriate facilities. Contain dirty water for re-use or treatment. Maintain dirty water management measures to ensure that design capacity is available.
Pollution due to run-off	High	Low	All dirty water must be retained within the process water system. Maintain dirty water management measures to ensure that the design capacity is available. Implement a drain maintenance programme, identifying all critical water conveyance, treatment (e.g. separators) and storage facilities, and ensure regular inspections, maintenance and clean-out of these systems are done. Dirty stormwater run-off from road surfaces will need to be properly managed to contain dirty runoff and minimise erosion. This stormwater run-off must flow into the dirty stormwater system.
Pollution due to leakages (tailings and process/wastewater)	Moderate	Low	In the event that a leakage occurs the following procedure will be followed: Immediately contain the spillage to prevent spreading to adjacent areas. Repair/replace leaking pipe Clean up spillage as soon as possible if applicable. Conduct regular inspection along pipeline routes to monitor integrity and take corrective action as may be required. Visual inspection of the pipelines should be done on a weekly basis.
Overflow of process water	Moderate	Low	Implement a silt management plan for the dams. Maintain sufficient freeboard in the dams to prevent overflow during wet conditions.

© 2025 Kongiwe Environmental (Pty) Ltd

Impact/risk summary	Risk rating pre-mitigation	Risk rating post mitigation	Management measure
			Conduct regular maintenance to ensure that design capacities are maintained. Remove material stockpiled next to the dams and rehabilitate the footprint if required. Assess the trenches to verify if they have adequate capacity for water flow. Maintain trenches to keep out all vegetation and blockage that may prevent water flow to the return water dam.
Biodiversity			
Visual impact of the mine and its related activities.	Moderate	Low	Disturbed areas are to be rehabilitated by either defining a predetermined sustainable end land use or with natural grass species that are found on the property. Re-vegetate with plant species that are endemic to the area to reduce any latent visual impacts (the plants should blend in with the surrounding vegetation) and to enhance the probability that the plants will survive in the long term in this specific climatic environment. Rehabilitated land to be landscaped to blend in with surroundings.
Compaction due to road traffic to and from the tanks	Moderate	Low	Vehicles may only drive on designated roads. No unnecessary driving in the veld will be allowed.
Alien vegetation management	Moderate	Low	Develop and implement an alien vegetation eradication programme to manage alien invasive vegetation.
Erosion	Moderate	Low	Measures to be taken to reduce erosion due to runoff water will need to consider impacts of climate change on storm frequency and intensity.
Waste management			
Pollution due to hazardous material – leakages and spillages	Moderate	Low	All hazardous substances must be stored in a container which is clearly labelled with the adequate spill kits available. The mine must be in possession of a material safety data sheet as provided by the manufacturer. No hazardous material, including oil, paint, fuel and material containing hazardous substances may be stored outside of demarcated areas. Hazardous liquid such as oil, paint and fuel must be stored in a secured and bunded area. All drums containing hazardous material must be kept in good order. No damaged drums

© 2025 Kongiwe Environmental (Pty) Ltd

Impact/risk summary	Risk rating pre-mitigation	Risk rating post mitigation	Management measure
			will be allowed to be used. All material containing hazardous waste generated must be removed to the hazardous waste site. In the event that a spill occurs the following procedure will be followed: – Immediately contain the spillage to prevent spreading to adjacent areas. – Once the spill has been contained use absorbent material (such as GP cleaning powder) obtainable from the workshop to absorb the spilled material. – Dispose of absorbent into hazardous waste bin provided at the site. – Remove contaminated soil and dispose of as per the waste management procedure.
Pollution due to oil mixing with water	Moderate	Low	All polluted water must either flow into the process water system or be separated by an oil separator. All dirty water must be retained within the process water system.

Table 5-17 below represents the findings of the DWS' Risk impact Matrix. This table is scored by the specialist according to the various aspects of the operation and how they impact various indicators, the methodology is explained above. This table is then used by the DWS officials to determine what type of assessment and licence might be required. The scores awarded in the table then indicate the possible risk that the various activities might have on the surrounding water bodies and environment, and to what extent the risk can be mitigated via mitigation measures.

© 2025 Kongiwe Environmental (Pty) Ltd

Table 5-17: Scoring of Impact Severity, Spatial Scale and Duration to Determine Level of Consequence

Aspect	Flow Regime	Physico & Chemical (Water Quality)	Habitat (Geomorph + Vegetation)	Biota	Severity	Spatial scale	Duration	Consequence
Dirty Water Facilities (Pollution Control Dams, Return Water Dams)	1 (1)	5 (3)	3 (2)	5 (3)	3,5 (2,25)	3 (2)	4 (2)	10,5 (7,25)
In-Channel Clean Water Impoundment	4 (3)	2 (2)	5 (3)	4 (3)	3,75 (2,75)	2 (2)	4 (3)	9,75 (7,75)
Off-Channel Clean Water Impoundment	3 (2)	2 (2)	1 (1)	2 (2)	2 (1,75)	2 (2)	4 (3)	8 (6, 75)
TSF Complex	4 (4)	5 (4)	5 (4)	5 (4)	4,75 (4)	3 (3)	5 (4)	12,75 (11)
Waste Rock Dump	2 (2)	4 (3)	4 (3)	4 (3)	3,5 (2,75)	3 (3)	4 (3)	10,5 (8,75)
Operation of Underground Mining Areas	3 (3)	2 (2)	3 (3)	3 (2)	2,75 (2,5)	2 (2)	3 (2)	7,75 (6,5)
Stormwater Management	4 (3)	4 (3)	3 (3)	3 (3)	3,5 (3)	2 (2)	2 (2)	7,5 (7)
Maintenance of Roads and Traffic	2 (2)	3 (3)	3 (3)	3 (3)	2,75 (2,75)	3 (3)	3 (3)	8,75 (8,75)
Operation of Sewage Treatment Works	3 (3)	4 (3)	3 (3)	4 (3)	3,5 (3)	3 (3)	4 (3)	10,5 (9)
Shaft Associated Infrastructure	2 (2)	3 (2)	3 (3)	3 (2)	2,75 (2,25)	3 (2)	4 (3)	9,75 (7,25)

© 2025 Kongiwe Environmental (Pty) Ltd

Table 5-17: Scoring of Likelihood (Multiplied by the Consequence Score) to Calculate Significance Rating

Aspect	Frequency of activity	Frequency of impact	Legal Issues	Detection	Likelihood	Significance	Risk Rating	
							Pre-Mitigation	Post Mitigation
Dirty Water Facilities (Pollution Control Dams, Return Water Dams)	5 (3)	3 (2)	5 (5)	3 (3)	16 (13)	168 (94,25)	**Moderate**	**Moderate**
In-Channel Clean Water Impoundment	5 (3)	3 (2)	5 (5)	2 (2)	15 (12)	146,25 (93)	**Moderate**	**Moderate**
Off-Channel Clean Water Impoundment	4 (3)	2 (2)	1 (1)	2 (2)	9 (8)	72 (54)	**Moderate**	**Low**
TSF Complex	5 (4)	4 (3)	5 (5)	4 (4)	18 (16)	229,5 (176)	**High**	**High**
Waste Rock Dump	5 (3)	3 (3)	5 (5)	2 (2)	15 (13)	157,5 (113,75)	**Moderate**	**Moderate**
Operation of Underground Mining Areas	5 (3)	3 (3)	5 (5)	3 (3)	16 (14)	124 (91)	**Moderate**	**Moderate**
Stormwater Management	3 (3)	3 (2)	5 (5)	3 (3)	14 (13)	105 (91)	**Moderate**	**Moderate**
Maintenance of Roads and Traffic	2 (2)	3 (3)	1 (1)	3 (3)	9 (9)	78,75 (78,75)	**Moderate**	**Low**
Operation of Sewage Treatment Works	4 (3)	3 (3)	5 (5)	3 (3)	15 (14)	157,5 (126)	**Moderate**	**Moderate**
Shaft Associated Infrastructure	3 (2)	3 (3)	1 (1)	3 (3)	10 (9)	97,5 (65,25)	**Moderate**	**Moderate**

Table 5-18 below indicates the various mitigation measures suggested by the specialists to aid in the mitigation of possible impacts on site.

© 2025 Kongiwe Environmental (Pty) Ltd

Table 5-18: Aspects and Potential Impacts Relevant to the Joel Operation

Phase	Activity	Aspect	Impact	Mitigation Measures
Operation of Mine	Operation of clean and dirty water systems	Dirty water facilities (RWD) In-channel clean water impoundment Off-channel clean water impoundment	The potential failure of the RWD infrastructure may result in leakages and possible contamination of surface and groundwater, increased flow into the watercourses, and lowered water quality (increase in salts and specific contaminants of concern and reduced pH) within the watercourses.	• Proactive monitoring to ensure structural integrity is maintained; • It is recommended that the infrastructure be regularly inspected for leaks, or more often should there be any sign or reports of a leak; and • Should leakage occur all possible steps are to be taken to prevent the pollution of the downgradient wetlands systems during repair.
	Stockpiles and surface storage of waste materials	TSF Complex Waste Rock Dump	Runoff during high rainfall events has the potential to result in sedimentation of water resources and the contamination of wetlands and water courses.	• Where feasible, stockpiles and hazardous waste storage areas must be bunded by either a cut-off trench directed to a PCD or via a berm. • Where feasible a sediment trap should be installed at the PCD and be regularly maintained to ensure the freeboard is maintained.
	Maintenance of the existing surface infrastructure such as office buildings, workshops, fences, roads and pipelines.	Operation of infrastructure associated with shafts and access	The operation of the ancillary infrastructure will impact the surrounding watercourses via direct runoff from hardened surfaces and materials from stockpiles and workshops. This runoff will likely contain contaminants and occur at elevated velocities. Impacts to be expected in this phase can largely be related to water quality and quantity impacts.	• Adequate stormwater infrastructure is required to separate clean and dirty water. • • Where feasible, clean water discharge into the environment should have energy dissipaters to reduce the potential of erosion during high rainfall events and subsequent sheet runoff.
	Operation of the underground mining areas	Underground mining	Potential destabilization of surrounding environment through the further excavation of underground mining corridors and subsequent potential subsidence of the land.	• Any areas where future decant points may be determined by a geohydrological assessment, need to be carefully managed throughout the life of the mine;

© 2025 Kongiwe Environmental (Pty) Ltd

Phase	Activity	Aspect	Impact	Mitigation Measures
				• Water levels need to be strictly managed to ensure they are kept below any decant level while ensuring that a significant cone of depression impact does not take place; and • If decant does occur, all water is to be treated to the background water quality values prior to release into the receiving environment.
	Operation and maintenance of the stormwater management system associated with the existing mining activities.	Stormwater management	Loss of catchment yield resulting from stormwater containment, leading to: Increased flood peaks as a result of formalisation and concentration of surface runoff in clean water diversion structures; Potential for erosion, leading to sedimentation of the watercourses; Reduction in volume of water entering the watercourses, leading to loss of recharge of the watercourses; Altered vegetation community structure and diversity due to moisture stress and changes to goods and service provision.	• Clean and dirty water systems must be kept separate in line with Regulation GN704; • Where feasible, runoff from areas within the dirty water area should be captured in the sump and pumped to a PCD that is lined with an appropriate liner, before being re-used as process water of the mine, therefore all future PCD's must be lined; • Where feasible, all clean water diversions should be designed to accommodate the peak flow expected for at least a 1:50 year event; • Where feasible, the stormwater outlet should be constructed from energy dissipating structures (such as Armorflex or reno mattresses) to slow down the velocity of water inflow into the wetland; and

© 2025 Kongiwe Environmental (Pty) Ltd

Phase	Activity	Aspect	Impact	Mitigation Measures
				• After construction of the outlet, the area surrounding the outlet should be re-seeded with indigenous wetland vegetation.
	Operation of Sewage Treatment Works	Discharge of water	Potential discharge of untreated water or water that does not meet required standards resulting in water quality perturbations, downstream nitrification. Increased flows resulting in habitat modification and erosion.	• All discharged water is required to meet stipulated water quality guidelines. • Energy dissipaters are required as the outfall to negate erosion and downstream sedimentation and should be installed if not already in place. • Routine monitoring of outfall is required.

© 2025 Kongiwe Environmental (Pty) Ltd

The impacts listed above have the potential to compromise the drivers and responders of the system, with the following water resource features potentially be compromised:

- Indirect loss of wetlands;
- Instream sedimentation;
- Loss of biodiversity;
- Loss of aquatic biota;
- Loss of aquatic vegetation;
- Water quality impairment;
- Bioaccumulation of heavy metals;
- Drainage patterns change; and
- Altering overland flow characteristics.

It should be noted that during the mining and related operations the impact mitigation hierarchy was considered as per Figure 5-2. Due to the historicity of the activities occurring within the Harmony free State Operations, which comprise of five separate operations, only the operational phase of the activities was considered. A large number of the water resources occurring within the project area have not been directly impacted by the mining operations up to date, as they were constructed outside of the 500 m regulated area. There were however those areas which were avoidable, where mining-related infrastructure traverse these watercourses. This reflects that the 'avoid' principle of the mitigation hierarchy was taken into account possible. Due to the nature of the Project with multiple aspects representing legacy issues of pollution, and every aspect being applied for being existinginfrastructure, mitigation and rehabilitation is limited, with a comprehensive rehabilitation plan suggested to be drafted for the decommissioning phase of the mining operations.

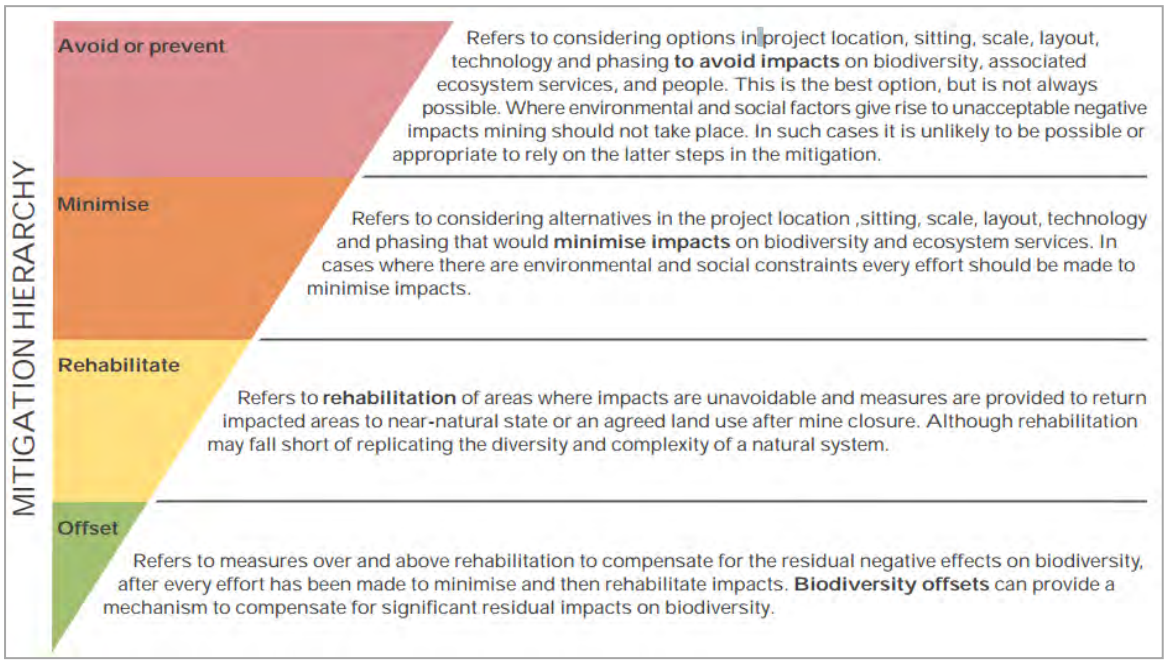


Figure 5-2: The Mitigation Hierarchy as described by the DEA (2013)

© 2025 Kongiwe Environmental (Pty) Ltd

5.9 Unplanned Events

The existing activities have potentialimpacts as discussed above; however, unplanned events may occur on any project and may have potential impacts which will need management. Table 5-19 is a summary of the findings of an unplanned event assessment from a water resource perspective. Note, not all potential unplanned events may be captured herein, and this must therefore be managed throughout all phases according to recorded pollution events.

Table 5-19: Summary of potential Unplanned Events that Require Attention

Unplanned Event	Potential Impact	Mitigation
Hydrocarbon spill into riverine habitat	Contamination of sediments and water resources associated with the spillage.	A spill response kit must be always available. The incident must be reported on and if necessary.
Uncontrolled erosion	Sedimentation of downstream river reach.	Erosion control measures and monitoring programme must be put in place.
Subsidence	Hydrological modification and resultant riverine habitat quality deterioration.	Subsidence risk assessment, avoidance of high-risk areas, post closure subsidence monitoring. Should subsidence occur, a suitable management plan must be investigated, this may include the construction of water diversion around subsidence areas to avoid surface water loss. The required mitigation would however be site specific.
Acid Mine Drainage	Severe water quality degradation	Water treatment, post closure water monitoring and water level management.

5.10 Best Practice Assessment

The BPGs that apply to the Joel Operation and where the requirements are addressed in this IWWMP are presented in Table 5-20.

Table 5-20: BPGs Applicable to the Joel Operations

BPG	Section reference in this IWWMP
A5: Water Management for Surface Mines	Table 6-1; Sections 2, 5 and 6
A4: Pollution control dams	Table 3-6; Table 6-1;
G1: Storm Water Management	Table 6-1; Sections 2.6.3 and 5.4
G2: Water and Salt Balances	Section 5.5
G3: Water Monitoring Systems	Sections 5.8 and 6.7
G4: Impact Prediction	Section 5.9
G5: Water Management Aspects for Mine Closure	Section 6.7
H1: Integrated Mine Water Management	This IWWMP
H2: Pollution Prevention and Minimisation of Impacts	Section 5.9, Table 6-1
H3: Water Reuse and Reclamation	Section 5

© 2025 Kongiwe Environmental (Pty) Ltd

5.11 Public Participation

The Public Participation Process (PPP) has been developed to ensure compliance with the IWULA process. The PPP offers stakeholders a fair opportunity to be informed about the Project, to raise issues of concern and to make suggestions for enhanced project benefits. The project team will considerall relevant issues and suggestions during the IWULA process.

The primary objectives of the PPP include:

- Meaningful and timeous participation of interested and affected parties (I&APs).
- Identification of issues and concerns of key stakeholders and I&APs with regard to the proposed development, i.e. focus on important issues.
- Promotion of transparency and an understanding of the Project and its potential environmental (social and biophysical) impacts.
- Accountability for information used for decision-making.
- Serving as a structure for liaison and communication with I&APs.
- Assisting in identifying potential environmental (social and biophysical) impacts associated with the proposed development.
- Inclusivity (the needs, interests and values of I&APs must be considered in the decision-making process).

Issues and responses documented during the public consultation process can be seen in the Comments and Responses Report (CRR) within the Public Participation (PP) Report attached as Appendix C.

5.12 Matters Requiring Attention / Problem Statement

The Key issues to be addressed are:

- The licensing of the activities triggering the 21 (a), (b), (f), (g), (j), (c) and (i) activities.
- Adequate clean and dirty water separation in terms of Regulation 704 and BPG G1.

Progress with addressing the key aspects above is provided in Section 6, together with a schedule for implementation of the remaining actions to ensure ongoing improvements and optimisation of water management.

6. Water and Waste Management

6.1 Water and Waste Management Philosophy

Harmony is a values-driven company and incorporates the following values that relate to the environment at the Harmony operations:

- Harmony respects the environment.
- Harmony is committed to continually improve on their processes in order to prevent pollution, minimise waste, increase their carbon efficiency and make use of natural resources.
- Harmony will develop innovative solutions to mitigate environmental and climate risks.

© 2025 Kongiwe Environmental (Pty) Ltd

6.2 Strategies

6.2.1 Water Management Strategy

Harmony has compiled its own Water Management Strategy. According to this strategy, water is considered to be critical to Harmony's business and the security of water supply is vital to the company's growth . The strategy is based on the following principles:

- Water conservation and water demand management.
- Harmony recognises that South Africa is a water-scarce country and water is a competing resource. The conservation of surface and groundwater, both quality and quantity, is integral to Harmony's planning process.
- Integrating water management and efficiencies. All new mining developments consider water management at all phases of the developments.
- Harmony recognises water as a critical resource for local communities and that early and consistent community engagement and investment is valuable to its operations and the implementation of projects. Harmony aims to understand and manage the company's operations to avoid impacts on communities and will provide support where possible. Local communities are always included in Harmony's risk assessment consultation process to ensure that the risk of water unavailability is managed appropriately.
- Acknowledging water in respect to climate change. Harmony's operations plan and design for adaptations to climate change, which drive the conservation and design criteria for the storage and treatment of water in areas that have increased or reduced rainfall. This also ensures that appropriate adaptation measures are in place to sustainably respond to changing climatic parameters.
- Water management at mine closure. Latent and residual impacts of mining activities, including the impact on water resources and water bodies are taken into consideration during mine closure planning. Harmony is committed to addressing mine closure in a holistic manner. Current water usage and discharge activities are monitored, and the future scenarios and the impact of the operations on water from a regional perspective are considered. Legacy issues around acid mine drainage are also considered as part of the decommissioning and closure programmes.

A number of programmes have been developed by Harmony to assist in achieving improved water performance, which include:

- A water standard that articulates good practice and minimum expectations for responsible water management.
- Group targets that cascade down to operational targets to drive continual improvement.
- Harmony is actively driving integrated water management and regional water management to optimise water use and promote a holistic approach to water in the group.
- Legacy acid mine drainage issues are being addressed through regional strategies with Harmony's own operations and peers[1].

6.2.2 Waste Management Strategy

Harmony has compiled its own Waste Management Strategy. This strategy was developed to establish and implement a waste management procedure applicable to individuals and companies that are involved in the sorting, loading, transporting, recycling and disposal of waste products generated from the various Harmony operations in compliance with the environmental legislation and requirements.

[1] No acid mine drainage issues have been identified at the Joel Operation.

© 2025 Kongiwe Environmental (Pty) Ltd

The waste management hierarchy of controls will be considered during the planning of new activities, and these controls must also be considered in a proactive manner for existing activities. The following should be considered to ensure that the hierarchy of controls is considered:

- **Waste prevention**: Is it possible to prevent the generation of waste?
- **Waste minimisation:** Is it possible to minimise the waste?
- **Resource recovery:** Is it possible to recover or recycle the waste?
- **Waste treatment:** Is it possible to treat the waste, reducing the waste or its toxicity?
- **Waste disposal**: If the waste being generated cannot be prevented, minimised, recovered/recycled or treated it must be disposed of at a suitable waste disposal facility.

6.3 Performance Objectives/ Goals

6.3.1 Water

Harmony has set the following objectives based on the Water Management Strategy:

- **Improving water efficiency:** Harmony aims to conserve water as a natural resource by improving the company's water efficiencies through reuse and recycling. Internal targets and peer benchmarking guide Harmony's aim to work efficiently, as these relate to water usage.
- **Protecting water:** The nature of mining impacts on the receiving environment, therefore Harmony prioritises the management of water to ensure that the company operates with the requirements for future generations in minds. Harmony aims to reduce its impact on surface and groundwater from a water quality perspective through the following:
    - Remediating contamination;
    - Pro-actively preventing pollution;
    - Managing water at source; and
    - Gearing all operations to zero discharge for all South African Operations.
- **Accounting for the value of water:** Harmony recognises the need for water use in terms of current operations, especially regarding the impact of climate change on its future growth strategy. Harmony also recognises that water management and accountability require an interdisciplinary and multidisciplinary synthesis in order to achieve success.
- **Partnerships for success**: Multi-stakeholder engagement is required with technical partners, communities, government and industry partners. Harmony recognises that its operations compete with other local users for water resources and the company therefore engages with important stakeholder groups of other users to minimise the potential for competition and conflict over the scarce resource. Harmony is therefore facilitating water management with local government to try and assist the managing of sanitation and water clean-up.

Harmony has set the following aims to give effect to the Water Management Strategy:

- To comply with all relevant legislation in the host countries in which Harmony operates.
- To conserve the natural resources by improving the company's water efficiencies through reuse and recycle. Ensuring that the water is treated and discharged into the receiving environment should it be required for it to be returned to the source.
- Groundwater systems would be conserved as far as practicable by:
    - Understanding the impact of Harmony's operations on the fissure water;
    - Limiting Harmony's drawdown;
    - Eliminating where possible potential impacts to the groundwater; and
    - Monitoring and controlling possible plumes.

© 2025 Kongiwe Environmental (Pty) Ltd

- Surface water will be conserved as far as practicable by:
- Pre-empting the impact from Harmony's mining operations on surface water sources.
- Limiting Harmony's operational dependency on potable and freshwater resources.
- Limiting Harmony's discharges and, where possible, drive a zero-discharge philosophy.

6.3.2 Waste

Harmony aims to implement an integrated waste management system for the management of waste material, as per DWS and DFFE's requirements, as well as the Waste Management Strategy for the Harmony Operations. The must be adhered to at the Harmony operations to ensure the effective management of waste:

- Waste management practices must take cognisance of the waste management hierarchy as required by DWS and DFFE; and
- A waste management assessment must be undertaken.

6.4 Measures to Achieve and Sustain Performance Objectives

All objectives and targets set related to water and waste management are captured in Harmony's EMS and are driven through action plans. Part of the system entails an annual review to assess progress against targets and objectives.

6.5 Options Analysis and Motivation for Preferred Options

The processing activities, facilities and associated water uses at the Joel Operation are all existing, therefore an option analysis and motivation for preferred options is not applicable.

6.6 IWWMP Action Plan

Operational Action Plans have been developed to address aspects at the operations requiring attention or additional measures. The Action Plans for 2025/26 are presented in Table 6-1 and will be reviewed on an annual basis.

Table 6-1: Operational Action Plan for the Joel Operation

Aspect	Actions	Timeframe
GN704 Audit	Conduct a GN 704 Audit.	December 2027
Metering	Ensure adequate metering is implemented for all water uses to assist with an improved water balance	December 2027
Salt balance	Develop a salt balance for the Joel Operation.	December 2027
Stormwater management	Implement site-specific Storm Water Management Plan for the Joel Operation.	December 2027
	Operate and maintain dam levels to prevent spillages to the clean environment.	Ongoing
Waste	Undertake a geochemical assessment to characterise the waste rock and tailings at the operations.	December 2027
	Implement and maintain waste management facilities.	Ongoing
Waste rock	Reclaim and/or rehabilitate the remaining waste rock dumps in line with the mine closure plan (if possible).	Life of mine

© 2025 Kongiwe Environmental (Pty) Ltd

Aspect	Actions	Timeframe
	Rehabilitate footprint areas and ensure the rehabilitated areas are free draining (if possible).	Life of mine
Water quality	Compile an annual report to interpret the surface and groundwater quality monitoring results.	Annually
	Compare water quality results to background quality, the Reserve and the WUL limits (once received).	Ongoing
Biomonitoring	Undertake yearly, seasonal biomonitoring and toxicity testing on the surrounding sensitive and impacted environments.	Once WUL is issued
Monitoring and maintenance	Undertake continuous monitoring and maintenance of the pipelines on site	Ongoing
Management procedures	Ensure the continued implementation of all emergency and spill prevention and mitigation action plans on site.	Ongoing

6.7 Control and Monitoring

6.7.1 Operational Phase

Surface and Groundwater monitoring will continue throughout the operational phase. Data from water quality and flow monitoring should continue to be assessed against the WUL compliance limits (once received) and subjected to trend analysis.

6.7.2 Post-Closure Phase

Monitoring post closure will need to include:

- Surface water: Quality monitoring against parameters as required by the WUL, and as per agreement with DWS.
- Groundwater: Quality monitoring of both the shallow and deep aquifers against the parameters required by the WUL. Sampled as per agreed frequency for a five-year post-closure period.
- Erosion monitoring: Should this be required, an erosion monitoring plan will be developed considering the developing of a representative reference site on the disturbed footprints and undertaking visual and topographic assessments to determine erosion rate, using standard erosion monitoring techniques and monitoring period.
- Vegetation establishment: Vegetation conditions should be monitored using standard field techniques to determine whether the vegetation has been established with a species composition and density similar to that of a reference analogue site established in a similar ecotype, conducted annually for a five-year post-closure period.
- Biomonitoring and Toxicity Testing: Quality monitoring against parameters as required by the WUL. As per agreed period during closure application.
- Rehabilitation Performance Monitoring: Rehabilitation performance monitoring should be undertaken using standardised approaches. This should include comparing the reclaimed areas to analogue sites of pre-mining vegetation where vegetation and soil chemical and physical properties are measured.

Photographic records should be maintained together with findings, follow up actions and close out records. Annual reports should be prepared to document the results of the monitoring during the closure and post-closure phases.

© 2025 Kongiwe Environmental (Pty) Ltd

6.8 Monitoring of Change in Baseline Information

The groundwater and surface water quality is monitored. Monitoring will be undertaken as per the monitoring programmes, as described in in the mines water quality monitoring plans. Change in the data will be monitored relative to the baseline conditions. Should contamination (concentrations exceeding the applicable WUL limits or outside of the baseline range, whichever is consider appropriate for the area) or reduction in water supply be detected, Harmony will notify the Regional Director of DWS, as required by the WUL and institute corrective actions, as described in in this report.

6.9 Audit and Report on Performance Measures

An EMPr audit has been undertaken in 2025. It is advised that when the WULs are awarded, annual WUL audits must be undertaken.

6.10 Audit and Report on Relevance of IWWMP Action Plan

No audits against the IWWMP have been conducted, but progress with implementation will be provided in the annual updates which will be submitted to DWS.

7. Conclusion

The WULA for the Joel Operation has considered the current DWS requirements and all supporting information as available is included either in the main text or as appendices to this IWWMP. Harmony is committed to implementing the scheduled actions and recommended mitigation measures to address any potential impacts.

7.1 Regulatory Status of Activity

The Joel Operationis currently operating without a WUL or GN R704 Exemption. This WULA covers the existing activities at the Joel Operation, associated Section 21 (a), (b), (f), (g), (j), (c) and (i) water uses and exemption from GN704.

7.2 Statement on Water Uses requiring Authorisation, Dispensing with Licensing Requirement with possible Exemption from Regulations

All water uses at the Joel Operation require authorisation in terms of the NWA. The Section 21 water uses included in the IWULA, requiring authorisation are Section 21 (a), (b), (f), (g), (j), (c) and (i) water uses:

- Taking of water from a water resource,
- Storing water,
- Discharging waste or water containing waste into a water resource through a pipe, canal, sewer or other conduit,
- Disposing of waste in a manner which may detrimentally impact on a water resource – wastewater dams, waste rock dumps, dust suppression, stormwater dams, return water dams and tailings dams,
- Removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people dewatering from underground workings,
- Impeding or diverting the flow of water in a watercourse and
- Altering the bed, banks, courses or characteristics of a watercourse.

GN R704 of the NWA provides regulations on the use of water for mining and related activities aimed at the protection of water resources. The regulations came into effect on 4 June 1999. In terms of regulation 3 of GNR

© 2025 Kongiwe Environmental (Pty) Ltd

704, exemption from the requirements of regulations 4, 5, 6, 7, 8, 10 or 11 may be applied for through a motivation to the DWS. Exemption should be acquired as stipulated by this report.

© 2025 Kongiwe Environmental (Pty) Ltd

8. References

AquiSim Consulting (October 2025), 2025 Harmony Free State Operations Groundwater Flow and Mass Transport Model Update. Report Reference: ASC-1018F-6, Pretoria.

DWS (April 2016), Classes and Resource Quality Objectives of Water Resources for Catchments of the Middle Vaal. Report Reference: 469, Pretoria.

DWS (December 2018), Proposed Reserve Determination of Water Resources for the Vaal Catchment. Report reference: 42127, Pretoria.

Department of Water and Sanitation (DWS). 2019. Determination of Water Resource Classes and Resource Quality Objectives for Mokolo, Matlabas, Crocodile (West) and Marico Catchments. Notice 526 of 2019. Government Gazette: No:42775. 18 October 2019

Department of Water Affairs and Forestry (DWAF) 2005. Final draft: A practical field procedure for identification and delineation of wetlands and Riparian areas.

Department of Environment, Forestry and Fisheries (DEFF), 2022. Screening Report for an Environmental Authorization or for a Part Two Amendment of an Environmental Authorisation as Required by the 2014 EIA Regulations – Proposed Site Environmental Sensitivity

Department of Water and Sanitation. 2014. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Secondary Catchments in South Africa. Secondary: C23K. Compiled by RQIS-RDM: https://www.dwa.gov.za/iwqs/rhp/eco/peseismodel.aspx. Accessed on 05 February 2022.

Department of Water Affairs (DWA). 2011. Procedures to Develop and Implement Resource Quality Objectives. Department of Water Affairs, Pretoria, South Africa

EIMS (March 2019), Environmental Management Programme MVH, Unisel, Saaiplaas, Masimong, Brand. Report Reference: 30/5/1/2/2/82 MR, Johannesburg.

Harmony (June 2018), Social and Labour Plans 2018 to 2022.

Hydrospatial (Pty) Ltd. (2023). 2023 Surface Water Study for the Harmony Gold Mining Free State Operations NWA Section 21 (c) and (i) Water Uses Project. Johannesburg.

Jones & Wagener (May 2017), Harmony Gold Free State Operations Integrated Water and Waste Management Plan. Report Reference: JW134/16/F141 – Rev 1, Johannesburg.

LDM (2017), Lejweleputswa District Municipality – Integrated Development Plan 2017-2022.

Republic of South Africa (RSA) 2016. Classes and resource quality objectives of water resources for catchment of the Middle Vaal. 22. No. 39943. Published in Government Gazette No. 469 dated 22 April 2016.

Shangoni Management Services (March 2010), Harmony Gold Mining Company Limited Environmental Management Programme. Report Reference: FS 30/5/1/2/2/82 MR, Pretoria.

© 2025 Kongiwe Environmental (Pty) Ltd

Water Research Commission (WRC) (April 2013), Groundwater Reserve Determination for the Middle Vaal Water Management Area. Report Reference: KV313/13.

9. Appendices

© 2025 Kongiwe Environmental (Pty) Ltd

Appendix A: Master Layout Plan

26°48'30"E
26°50'25"E
28°14'50"S
28°16'40"S

Inset Map

Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

HARMONY:
JOEL
MASTER LAYOUT

Legend

- Groundwater Monitoring
- Surface Water Monitoring

Section 21

- Section 21 (a)
- Section 21(b)
- Section 21(c) and (i)
- Section 21(f)
- Section 21(g)
- Section 21(j)
- Rivers
- 50-Year Floodlines
- 100-Year Floodlines
- Joel Operation Boundary
- Wetlands 500m Buffer
- Wetlands

Infrastructure

- Trenches
- Overhead Electricity
- Pipelines

0 0.25 0.5 1 1.5
Kilometers

Project Code: HARM#010
Client: Harmony Gold
Drawn: C Strooh | Checked: Z Omar
© 2025 Kongiwe Environmental (Pty) Ltd
www.kongiwe.com | Date: 11 November 2025

1:22 000

Coordinate System: WGS84 Lo 27
Projection: Transverse Mercator
Datum: WGS 1984

(A3)
2024 Satellite Imagery

Disclaimer
The information represented in this plan is for general information purposes only and is subject to change.

FILE REF:
Z:\GIS\Projects\Harmony_ Gold\Harmony\Joel\Projects \Joel Operations Revised Water Uses 2025 A3 Landscape.mxd

Appendix B: Water Resource Baseline and Risk Assessment

Water Resource Baseline and Risk Assessment for the Harmony Free State Operations

Welkom, Free State, South Africa

July 2022

Last amended: August 2025

CLIENT

REFERENCE

CL202109(08) DG

Prepared by:

The Biodiversity Company

Cell: +27 81 319 1225

Fax: +27 86 527 1965

info@thebiodiversitycompany.com

www.thebiodiversitycompanycom

Report Name	Water Resource Baseline and Risk Assessment for the Harmony Free State Operations
Submitted to	KONGIWE
Report Reviewer & Updates	Andrew Husted (Pr. Sci. Nat. 400213/11) Andrew Husted is Pr Sci Nat registered (400213/11) in the following fields of practice: Ecological Science, Environmental Science and Aquatic Science. Andrew is an Aquatic, Wetland and Biodiversity Specialist with more than 15 years' experience in the environmental consulting field.
Report Writer	Michael Ryan (Cand. Sci. Nat. 128125) Michael Ryan is an Aquatic Ecologist and Hydrologist with 4 years of experience in baseline river assessments and aquatics, with his SASS5 accreditation. Michael Ryan received his B. Sc Honours degree (Geography) from the University of Witwatersrand. Michael specialises in surface water monitoring and aquatic systems and floodline determination. Michael has experience in projects analysing water quality and hydrology which include pipelines; dams; road upgrades; power stations; mining; etc
Declaration	The Biodiversity Company and its associates operate as independent consultants under the auspice of the South African Council for Natural Scientific Professions. We declare that we have no affiliation with or vested financial interests in the proponent, other than for work performed under the Environmental Impact Assessment Regulations, 2014, as amended. We have no conflicting interests in the undertaking of this activity and have no interests in secondary developments resulting from the authorisation of this project. We have no vested interest in the project, other than to provide a professional service within the constraints of the project (timing, time and budget) based on the principals of science.



Labeo umbratus sampled within the project area

Executive Summary

The Biodiversity Company was commissioned by Kongiwe Environmental (Pty) Ltd to conduct a Water Resource Baseline and Risk Assessment for the Harmony Free State Operations. The assessment was conducted to identify the current surface water resources including rivers, tributaries and wetlands; and determine the Ecological Importance and Sensitivity (EIS) of the surface water resources. This report will therefore aid in informing the process of receiving Environmental Authorisation (EA) through the Water Use Licence Application (WULA) (Sec 21 (c) and (i) activities) process for all five operations which constitute the Harmony Free State Operations (Central, Harmony One, Joel, Saaiplaas & Target Operations). The second aspect of the report was to establish an Aquatic Biomonitoring Programme to be implemented by the Harmony Free State Operations which could be incorporated into the subsequently issued WULs.

Baseline Environment:

Watercourses

Conclusions have been made according to river systems as a result of the multiple operations as well as the multiple river systems shared between these operations. The report has presented baseline conditions of all associated river systems related to the Harmony Free State Operations which has assisted in the determination of a suitable monitoring program for future sampling for the five separate operations. The river systems that were assessed for water quality only were done only to investigate their potential influence on systems within the project area and are summarized below. The listed operations and associated rivers include:

- Central Operations – Rietspruit River, Merriespruit River, Doring River, Sand River and Bosluisspruit River;
- Harmony One Operations – Rietspruit River, Mahem River, Sand River and Sandspruit River;
- Joel Operations – Doring River and Theronspruit River;
- Saaiplaas Operations – Rietspruit River, Mahem River, Sand River and – Doring River; and
- Target Operations – Sandspruit River and Losdoringspruit.

<u>Rietspruit River</u>

Water quality within the Rietspruit River indicated modified conditions with measured parameters outside of the prescribed Target Water Quality Ranges (TWQRs) and Resource Quality Objectives (RQOs). The modified water quality is noted by elevated electric conductivity (EC) in the system which is a result of upstream activities as elevated concentrations are noted upstream of the Harmony Free State Operations. However, a small increase is noted between SVC 03 and the New CP ESW which is downstream of the TSF associated with the southern section of the Harmony One Operations. The results of the instream habitat assessment for the Rietspruit River indicated category C or moderately modified habitat conditions; while the riparian habitat assessment indicated category D or largely modified habitat conditions. South African Scoring System 5 (SASS5) scores ranged from category B (largely natural) to category C (moderately modified). The increase in Average Score Per Taxa (ASPT) is attributed to habitat availability as water quality does not improve. Macroinvertebrate Response Assessment Index (MIRAI) scores for the system were derived as largely modified (category D); while FRAI scores were derived as seriously modified (category E) which is a result of degraded water quality in the system. The calculated Present Ecological State (PES) for the system was therefore largely to seriously modified (category D/E).

Doring River

Water quality within the Doring River indicated modified conditions with the measured parameters being outside of the prescribed TWQR and RQO. Upstream of the Joel Operations, water quality was measured to be compliant. However, water quality from the Theronspruit River, which flows through the western boundary of the Joel Operations, was identified as the source of modification. The Theronspruit River experiences modification from both the neighbouring Beatrix operations and the mining activities related to the Joel Operations. The results of the instream and riparian habitat assessments for the Doring River further indicated a category D or largely modified habitat condition. SASS5 scores ranged from category A (natural) to category C (moderately modified). Conditions upstream of the Joel Operations are considered category A (natural), with a degradation of the overall category of the system to category B (largely natural downstream).

Bosluisspruit River

Water quality within the Bosluisspruit River indicated modified conditions with measured parameters outside of the prescribed TWQR and RQO. This system was only assessed as a potential source of modification to the Doring River which it presented to be, with modification unrelated to the Harmony free state operations; but rather agricultural practices and alternative mining operations. SASS5 scores for the reach indicated category E/F which was a compounded result from modified water quality and poor habitat (14%). FRAI scores were derived as seriously modified (category E) with the only species sampled in the reach the alien Invasive *Gambusia affinis*.

Theronspruit River

The Theronspruit River, which was identified as the source of modification to the Doring River, was measured as moderately modified based on the macroinvertebrate community sampled. MIRAI scores for the system were derived as category D (largely modified); while FRAI scores were derived as seriously modified (category E). This was a result of all three drivers (flow, habitat and water quality), which were largely modified, contributing to the modified macroinvertebrate communities. The resultant PES for the Doring River was therefore calculated to be category D (largely modified).

Sand River

Water quality within the Sand River indicated modified conditions with measured parameters being outside of the prescribed TWQR and RQO. The modified conditions are only observed downstream of the Central, Harmony One and Saaiplaas Operations which are suspected to have caused the modification of the system. The Rietspruit and Doring Rivers also present sources of modification to the system as they are affected by upstream mining (associated with the Harmony Free State Operations) and agricultural activities. The results of the instream habitat assessment for the Sand River indicated a category D or largely modified habitat conditions; while the riparian habitat assessment indicates a category E or seriously modified habitat conditions. These are significantly affected by the surrounding land uses such as mining and agricultural activities, as well as urban settlements. SASS5 scores ranged from category B (largely natural) to a category E/F (seriously modified) and indicate an overall downstream degradation of the system with high abundances noted upstream. Sites SVC 10/Mostert 12/ ESW 54, which present a cumulative influence of upstream mining activity, are considered a category E/F or seriously modified. MIRAI scores for the system were derived as largely modified (category D); while FRAI scores were derived as category E (seriously modified). This has resulted in the PES being Largely to category D/E (Seriously Modified) which is predominantly due to diminished water quality in the system.

Mahem River

Water quality within the Mahem River indicated modified conditions with measured parameters outside of the prescribed TWQR and RQO. Water quality throughout the reach and associated tributaries is modified and indicates a direct influence from associated mining activities from the Central, Harmony

One and Saaiplaas operations. The results of the instream and riparian habitat assessment in the Mahem River indicated a category E or seriously modified habitat conditions in the watercourses and its tributaries. The modification to the system has resulted in the discontinuity of the River from the downstream Vet River. SASS5 scores for the system were a category E/F (seriously modified) which is caused by a combination of habitat availability and modified water quality. There was no calculated PES for the Mahem river due to lack of surface flow and access to the reach.

Sandspruit River

Water quality within the Sandspruit River indicated modified conditions with measured parameters outside of the prescribed TWQR and RQO. The Sandspruit River doesn't indicate modification from the Target or Harmony One Operations. However, the source of the recorded modification at SVC 17 is unknown with locating it outside the scope of the report. The noted modification within the Losdoringspruit is however directly attributed to the mining activities associated with the Freddie's Waste Rock Dump (WRD) of the Target Operations. The results of the instream habitat assessment for the Sandspruit River indicated a category D or largely modified habitat conditions; while the riparian habitat assessment indicated a category C or moderately modified habitat conditions. Surrounding agricultural activities have a large influence on the system. SASS5 scores ranged from category B (largely natural) to category C (moderately modified). Both sites (SVC 15 and SVC 16) indicate largely natural conditions with a noted degradation found at SVC 17. This further reinforces that there is no noted modification resulting from the Target or Harmony One Operations. MIRAI and FRAI scores for the system were both derived as largely modified (category D). This was a result of flow and water quality modification and resulted in a PES that is largely modified.

Risk Assessment

A variety of risks have been identified for the separate operations which constitute the Harmony Free State Operations according to the infrastructure relevant to the separate operations. Due to the nature of the project, that is one of an application for a WUL for existing infrastructure, only the operational phase of these projects was considered. These various aspects scored "Moderate" and "High" pre-mitigation significance ratings with some expected to remain "Moderate" and "High" after mitigation due to the continued contamination of the watercourse through surface and groundwater systems and the elevated risks these activities pose to the water resources within the project area. These risks can be minimally mitigated, however are unavoidable with many resulting from legacy issues. This highlights the importance of a comprehensive rehabilitation plan for the decommissioning phase of the separate mining operations.

Table of Abbreviations/Acronyms

Abbreviations	Abbreviated Word
ASPT	Average Score Per Taxa
BAR	Basic Assessment Report
CBA	Critical Biodiversity Area
CR	Critically Endangered
DO	Dissolved Oxygen
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EAP	Environmental Assessment Practitioner
EC	Electrical Conductivity
ECO	Environmental Control Officer
EIA	Environmental Impact Assessment
EIS	Ecological Importance and Sensitivity
EN	Endangered
EMPr	Environmental Management Program
EPL	Ecosystem Protection Level
ETS	Ecosystem Threat Status
FEPA	Freshwater Ecosystem Priority Areas
FRAI	Fish Response Assessment Index
GA	General Authorization
GSM	Gravel, sand and mud
ha	hectares
HGM	hydrogeomorphic
IUCN	International Union for Conservation of Nature
IWUL	Integrated Water Use License
IHIA	Intermediate Habitat Integrity Assessment
LC	Least Concern
LDM	Lejweleputswa District Municipality
MIRAI	Macroinvertebrate Response Assessment Index
NBA	National Biodiversity Assessment
NEMA	National Environmental Management Act
NFEPA	National Freshwater Ecosystem Priority Areas
NT	Near Threatened
NWA	National Water Act
NWCS	National Wetland Classification Systems
NWM5	National Wetland Map 5
PCD	Pollution Control Dam
PES	Present Ecological State
RQOs	Resource Quality Objectives
S	Stones
SASS5	South African Scoring System 5
SQR	Sub Quaternary Reach
SWSA	Strategic Water Source Areas
TEC	Target Ecological Category
TSF	Tailings Storage Facilities
TWQR	Target Water Quality Ranges

Veg	Vegetation
VU	Vulnerable
WMA	Water Management Area
WULA	Water Use License Application

Table of Contents

1 Introduction 8
1.1 Terms of Reference 8
1.2 Background 9
1.2.1 Central 9
1.2.2 Harmony One 10
1.2.3 Joel 10
1.2.4 Saaiplaas 11
1.2.5 Target 11
2 Project Area 12
2.1 Hydrological Setting 12
2.2 Site Selection 14
3 Desktop Assessment 29
3.1 National Freshwater Ecosystem Priority Areas (NFEPA) 29
3.2 National Wetland Map 5 32
3.3 Status of Sub-Quaternary Reach's 32
3.3.1 Resource Quality Objectives 36
3.3.2 Strategic Water Source Areas 37
3.3.3 Freshwater Critical Biodiversity Area 37
3.3.4 Ecosystem Threat Status 38
3.3.5 Ecosystem Protection Level 39
3.4 Expected Fish Species 40
4 Limitations and Assumptions 42
5 Methodology 42
5.1 Wetlands Assessment 42
5.1.1 Identification and Mapping 42
5.1.2 Ecological Classification and Description 43
5.1.3 Determining Buffer Requirements 43
5.2 Aquatics Assessment 43
5.2.1 Water Quality 43
5.2.2 Habitat Assessments 43
5.2.3 Intermediate Habitat Integrity Assessment 44

5.2.4 Aquatic Macroinvertebrate Assessment 45
5.2.5 Fish Community Assessment 47
5.2.6 Present Ecological Status 48
5.3 Risk Assessment 48
6 Results and Discussions 48
6.1 Wetland Assessment 48
6.1.1 Delineation and Description 48
6.1.2 Unit Setting 48
6.1.3 Wetland Indicators 50
6.1.4 General Functional Description of Wetland Types 52
6.2 Aquatics Assessment 56
6.2.1 *In situ* water quality 56
6.2.2 Intermediate Habitat Integrity Assessment 78
6.2.3 Aquatic Macroinvertebrates 86
6.2.4 Fish Community Assessment 94
6.2.5 Present Ecological State 100
7 Monitoring programme 100
8 Water Resource Risk Assessment 104
8.1 Current Impacts 104
8.2 Risk Assessment 116
8.3 Unplanned Events 128
9 Conclusions 129
9.1 Watercourse 129
9.1.1 Rietspruit River 129
9.1.2 Doring River 129
9.1.3 Bosluisspruit River 130
9.1.4 Sand River 130
9.1.5 Mahem River 130
9.1.6 Sandspruit River 130
9.2 Risk Assessment 131
10 References 132

Tables

Table 2-1: Photos, co-ordinates and descriptions for the sites sampled for Central Operations (May 2022) 14

Table 2-2: Photos, co-ordinates and descriptions for the sites sampled for Harmony One Operations (May 2022) 16

Table 2-3: Photos, co-ordinates and descriptions for the sites sampled for Joel Operations (May 2022) 19

Table 2-4: Photos, co-ordinates and descriptions for the sites sampled for Saaiplaas Operations (May 2022) 20

Table 2-5: Photos, co-ordinates and descriptions for the sites sampled for Target Operations (May 2022) 22

Table 3-1: The NFEPA categories of the relevant catchments 29

Table 3-2: Summary of the Present Ecological State of the SQRs associated with the Harmony Free State Operations (DWS, 2014)- 33

Table 3-3: Resource Quality Objectives for the relevant catchments 36

Table 3-4: Expected fish species 41

Table 5-1: Criteria used in the assessment of habitat integrity (Kleynhans, 1996) 44

Table 5-2: Descriptions used for the Ratings of the Various Habitat Criteria 45

Table 5-3: Biological Bands / Ecological categories for interpreting SASS5 data (adapted from Dallas, 2007) 46

Table 5-4: Intolerance rating and sensitivity of fish species 47

Table 5-5: Significance ratings matrix 48

Table 6-1: In situ water quality results for the Central Operations (May 2022) 56

Table 6-2: In situ water quality results for the Harmony One Operations (May 2022) 61

Table 6-3: In situ water quality results for the Joel Operations (May 2022) 66

Table 6-4: In situ water quality results for the low flow survey (May 2022) 70

Table 6-5: In situ water quality results for the Target Operations (May 2022) 74

Table 6-6: Results for the Sandspruit River habitat integrity assessment 78

Table 6-7: Results for the Mahem River habitat integrity assessment 79

Table 6-8: Results for the Rietspruit River habitat integrity assessment 81

Table 6-9: Results for the Sand River habitat integrity assessment 82

Table 6-10: Results for the Merriespruit River habitat integrity assessment 83

Table 6-11: Results for the Doring River habitat integrity assessment 85

Table 6-12: Biotope weightings for the watercourse geoclasses 87

Table 6-13: Biotope diversity scores for the May 2022 assessment 87

Table 6-14: Biotope diversity scores for the May 2022 assessment continued 87

Table 6-15: Macroinvertebrate assessment results recorded for the Central Operations 90

Table 6-16: Macroinvertebrate assessment results recorded for the Harmony One Operations 90

Table 6-17: Macroinvertebrate assessment results recorded for the Joel Operations 91

Table 6-18: Macroinvertebrate assessment results recorded for the Saaiplaas Operations 92

Table 6-19: Macroinvertebrate assessment results recorded for the Target Operations 92

Table 6-20: MIRAI Score for the sampled systems (Main stems) 94

Table 6-21: Summary of the fish species sensitivity for the expected fish species list 95

Table 6-22: Presence/absence, of fish species for the sampled sites and FRAI results per reach 97

Table 6-23: Presence/absence of fish species for the sampled sites and FRAI results per reach 98

Table 6-24: Fish species sampled in the project area with associated pictures (May 2022) 99

Table 6-25: The Present Ecological Status of the rivers pertaining to the Harmony Free State Operations 100

Table 7-1: Monitoring Checklist for Harmony Free State Operations 102

Table 7-2: Selected methodology to be applied to each sampling site in future monitoring 103

Table 8-1: Key for the different activities occuring at each of the five Harmony Free State Operations. 105

Table 8-2: Aspects and impacts relevant to the activity 118

Table 8-3: DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Saaiplaas Operational Area 120

Table 8-4: DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Central Operational Area 121

Table 8-5: DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Harmony Operational Area 122

Table 8-6: DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Joel Operations 124

Table 8-7: DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Target Operations 126

Table 8-8: Summary of potential unplanned events that require attention 128

Figures

Figure 1-1: Separate boundaries for each of the five water use operational areas at Harmony Free State Operations 12

Figure 2-1: Locality map illustrating the Harmony Free State Operations 13

Figure 2-2: Hydrological context of the project area 13

Figure 2-3: Illustration of Central Operations sampling points 24

Figure 2-4: Illustration of Harmony One Operations sampling points 25

Figure 2-5:Illustration of Joel Operations sampling points 26

Figure 2-6: Illustration of Saaiplaas Operations sampling points 27

Figure 2-7: Illustration of Target Operations sampling point 28

Figure 3-1: Layout of the Harmony Free State Operations in relation to the riverine National Freshwater Priority Areas 31

Figure 3-2: NFEPA wetlands present within the project area 32

Figure 3-3: Illustration of the Desktop Present Ecological State within the project area 35

Figure 3-4: Illustration of the Freshwater Critical Biodiversity Areas within the project area (SANBI, 2008) 38

Figure 3-5: Illustration of the Ecosystem Threat Status of the project area (SANBI, 2018) 39

Figure 3-6: Illustration of the Ecosystem Protection Level of the project area (NBA, 2018) 40

Figure 5-1: Cross section through a wetland, indicating how the soil wetness and vegetation indicators change (Ollis et al. 2013) 43

Figure 5-2: Guidelines used for the Interpretation and Classification of the SASS5 Scores (Dallas, 2007) 46

Figure 6-1: Amalgamated diagram of a typical channelled valley bottom wetland, highlighting the dominant water inputs, throughputs and outputs, SANBI guidelines (Ollis et al. 2013) 49

Figure 6-2: Amalgamated diagram of a typical depression wetland, highlighting the dominant water inputs, throughputs and outputs, SANBI guidelines (Ollis et al. 2013) 49

Figure 6-3: Amalgamated diagram of a typical hillslope seep wetland, highlighting the dominant water inputs, throughputs and outputs, SANBI guidelines (Ollis et al. 2013) 50

Figure 6-4: Amalgamated diagram of a typical unchannelled valley bottom wetland, highlighting the dominant water inputs, throughputs, and outputs, SANBI guidelines (Ollis et al. 2013) 50

Figure 6-5: Hydrophytic vegetation identified within delineated watercourses. A) Cyperus spp. B) Kyllinga brevifolia C) Persicaria spp. D) Typha Capensis 52

Figure 6-6: Composite wetland delineation map for the Central Operations 54

Figure 6-7: Composite wetland delineation map for the Harmony One Operations 54

Figure 6-8: Composite wetland delineation map for the Joel Operations 55

Figure 6-9: Composite wetland delineation map for the Saaiplaas Operations 55

Figure 6-10: Composite wetland delineation map for the Target Operations 56
Figure 6-11: pH of each site associated with the Central Operations 59
Figure 6-12: EC of each site associated with the Central Operation 60
Figure 6-13: pH of each site associated with the Harmony One Operations 64
Figure 6-14: EC of each site associated with the Harmony One Operations 65
Figure 6-15: pH of each site associated with the Joel Operation 68
Figure 6-16: EC of each site associated with the Joel Operation 69
Figure 6-17: pH of each site associated with the Saaiplaas Operation 72
Figure 6-18: EC of each site associated with the Saaiplaas Operation 73
Figure 6-19: pH of each site associated with the Target Operations 76
Figure 6-20: EC of each site associated with the Target Operations 77
Figure 6-21: Aerial Imagery of the project area indicating land use along the Sandspruit River with the Target operation in Pink and Harmony One operation in purple (Google Earth 2022) 79
Figure 6-22: Aerial Imagery of the project area indicating land uses along the Sandspruit River with the Harmony One in purple and Saaiplaas Operation in blue, however there is overlap (Google Earth 2022) 80
Figure 6-23: Aerial Imagery of the project area indicating land uses along the Sandspruit River with the Central operation in yellow, Harmony One in purple and Saaiplaas Operation in blue, however there is overlap (Google Earth 2022) 82
Figure 6-24: Aerial Imagery of the project area indication land use along the Sandspruit River with the Central operation in yellow, Harmony One in purple and Saaiplaas Operation in blue, however there is overlap (Google Earth 2022) 83
Figure 6-25: Aerial Imagery of the project area indicating land uses along the Merriespruit River with the Central operation in yellow and Harmony One Operation in purple, however there is overlap (Google Earth 2022) 85
Figure 6-26: Aerial Imagery of the project area indicating land use along the Doring River with the Joel Operation in green (Google Earth 2022) 86
Figure 8-1: Depiction of all infrastructure within the 500 m regulated area at Central Operations 109
Figure 8-2: Depiction of all infrastructure within the 500 m regulated area at Harmony One Operations 110
Figure 8-3: Zoomed in depiction of all infrastructure within the 500 m regulated area at Harmony One Operations northern section 111
Figure 8-4: Zoomed in depiction of all infrastructure within the 500 m regulated area at Harmony One Operations southern section 112
Figure 8-5: Depiction of all infrastructure within the 500 m regulated area at Joel Operations 113
Figure 8-6: Depiction of all infrastructure within the 500 m regulated area at Saaiplaas Operations 114
Figure 8-7: Depiction of all infrastructure within the 500 m regulated area at Target Operations 115
Figure 8-8: The mitigation hierarchy as described by the DEA (2013) 117

DECLARATION

I, Michael Ryan declare that:

- I act as the independent specialist in this study;
- I will perform the work relating to the study in an objective manner, even if this results in views and findings that are not favourable to the applicant;
- I declare that there are no circumstances that may compromise my objectivity in performing such work;
- I have expertise in conducting the specialist report relevant to this study, including knowledge of the Act, regulations and any guidelines that have relevance to the proposed activity;
- I will comply with the Act, regulations and all other applicable legislation;
- I have no, and will not engage in, conflicting interests in the undertaking of the activity;
- I undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing any decision to be taken with respect to the study by the competent authority; and the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority;
- all the particulars furnished by me in this form are true and correct; and
- I realise that a false declaration is an offence in terms of Regulation 71 and is punishable in terms of Section 24F of the Act.



Michael Ryan

Riverine Ecologist and Hydrologist

The Biodiversity Company

July 2022

1 Introduction

The modification of land use within a river catchment has the potential to degrade local water resources (Wepener *et al.,* 2005). Land use change such as for agriculture thus has the potential to negatively impact on local water resources and ecosystem services. To manage water resources in South Africa holistically, the use of standard water quality sampling methods is considered in-effective. Non-point and point source pollutants are dynamic and can fluctuate according to several factors such as rainfall, industrial discharges, and extensive pollutant seepage. Aquatic ecology is permanently exposed to the dynamic conditions within water bodies and can therefore be an effective reflection of the environmental conditions within a management area. Considering this, the monitoring of aquatic ecology is regarded as an effective tool in water management strategies. This can therefore be used to assess the current state of a system.

The Biodiversity Company was commissioned by Kongiwe Environmental (Pty) Ltd to conduct a Water Resource Baseline and Risk Assessment for the Harmony Free State Operations. The assessment was conducted to identify the current surface water resources including rivers, tributaries, and wetlands, and to determine the Ecological Importance and Sensitivity (EIS) of the surface water resources. This report will therefore aid in informing the for the Water Use Licence Application (WULA) process for all five operations which constitute the Harmony Free State Operations (Central, Harmony One, Joel, Saaiplaas & Target Operations). The assessment is therefore in support of the required actions to apply for Section 21 (c) and (i) water uses, in terms of the National Water Act (No. 36 of 1998) (NWA), –for existing activities at the Free State Operations in the Lejweleputswa District Municipality, South Africa. The second aspect of the report was to establish an Aquatic Biomonitoring Programme to be implemented by the Harmony Free State Operations which could be incorporated into the subsequently issued WULs.

This assessment was conducted in accordance with the amendments to the Environmental Impact Assessment Regulations. 2014 (GNR 326, 7 April 2017) of the National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA). The approach has taken cognisance of the recently published Government Notices (GN) 320 (20 March 2020) and GN 1150 (30 October 2020) in terms of NEMA, dated 20 March and 30 October 2020: “Procedures for the Assessment and Minimum Criteria for Reporting on Identified Environmental Themes in terms of Sections 24(5)(a) and (h) and 44 of the National Environmental Management Act, 1998, when applying for Environmental Authorisation” (Reporting Criteria).

The purpose of the specialist studies is to provide relevant input into the basic assessment process and provide a report for the proposed activities associated with the project. This report, after taking into consideration the findings and recommendations provided by the specialist herein, should inform and guide the Environmental Assessment Practitioner (EAP) and regulatory authorities, enabling informed decision making, as to the ecological viability of the proposed project.

1.1 Terms of Reference

The Terms of Reference (ToR) included the following:

- Desktop description of the baseline receiving environment specific to the field of expertise (general surrounding area as well as site specific environment);
- Identification and description of any sensitive receptors in terms of relevant specialist disciplines that occur in the project area, and the manner in which these sensitive receptors may be affected by the activity;
- The delineation, classification and assessment of watercourses (rivers and wetlands) within 500 m of the project area:
    - The water quality;

  - The habitat quality;
  - The biological responses;

- Establish water resource baseline conditions to determine the current state of biotic and abiotic drivers as well as responders;
- Determination and categorisation of the ecological status of all potentially affected watercourses (EcoClassification);
- Determination and categorisation of the Present Ecological State (PES; health or integrity) of individual biophysical attributes, and then comparing these findings to the natural or close to natural reference conditions;
- The delineation and assessment of any potential sensitive areas;
- Establish an effective monitoring plan for the 5 divided mining operational areas which comprise the Harmony Free State Operations in which the selected sites for future monitoring are established as well as which methodologies to apply to each of the relevant sampling sites
- An impact assessment for the existing water use activities/ infrastructures; and
- The prescription of mitigation measures and recommendations for identified risks.

1.2 Background

The Harmony Free State Operations are owned by Harmony Gold Mining Company Limited (Harmony), located in the Free State Province within the Lejweleputswa District Municipality (LDM). The Free State Operations have been mining the Vaal Reefs since approximately 1950. The Harmony Free State Operations consist of five mines and processing plants namely Central, Harmony One, Joel, Saaiplaas & Target Operations which all comprise several shafts that are either operational, under care and maintenance or decommissioned. The extent of these operations is presented in Figure 1-1. Harmony has existing lawful water uses (previous valid permits / licences under Act 54 of 1956) in terms of the NWA and is currently applying for IWULs (Integrated Water Use Licences), in terms of NWA, 1998 – Section 21 (c) and (i) water uses, for each water use operational area at the Harmony Free State Operations.

1.2.1 Central

The Central Operations consist of the Central Plant and its associated supporting infrastructure that includes the metallurgical plant, which processes gold, and the various Tailings Storage Facilities (TSF). The total mining lease area of the Central Operations is approximately 22 583 ha in extent. Construction of the Central Plant began in July 1985 with the plant operational by September 1986. No mining is currently occurring at the Central Operations, as the plant mainly processes waste rock, old plant clean-ups and environmental clean-ups. This includes projects such as the Phoenix Project under which re-pulped tailings from FSS5 TSF is pumped to the Central Plant for processing. Currently the Central Operations mainly process:

- Reclamation of ARM 2 as well as Masimong 4 and Masimong 5 waste rock dumps which are delivered by rail;
- Re-pulped tailings from the hydraulic re-mining of FSS5 TSF which is delivered by pipeline;
- Carbon from the Saaiplaas Plant and Joel Plant- which is currently under Care and Maintenance; which is delivered by road; and
- Ad hoc environmental clean-ups which are delivered by road or rail (SRK Consulting 2020a).

1.2.2 Harmony One

The Harmony One Operations consist of the Harmony One Plant and nine shafts which are either operational or under care and maintenance or decommissioned (Unisel, Kudu/Eland, Nyala, Phakisa, Tshepong, Bambanani East, Bambanani West, Masimong 4 and Masimong 5 shafts) with a total mining lease area of approximately 37 622 ha. Harmony One Plant is the highest gold producing plant owned by Harmony in the region. The plant receives ore via rail from Masimong 5, Phakisa, Tshepong, Joel shafts as well as waste rock from the Freddie's 9 and Nyala waste rock dumps. Bambanani Shaft is under care and maintenance while Unisel Shaft is being decommissioned. The associated supporting infrastructure includes the Harmony One metallurgical plant, which processes gold, the associated TSFs, waste rock dumps and FSG 2 sewage treatment plant. A description of each shaft includes:

- The Tshepong Shaft is Harmony's largest operation which was initiated in 1986 and comprises of a single vertical shaft that extends to a depth of 2 154 m below surface;
- The Unisel Shaft extends to a depth of 2 153 m below surface to the gold-bearing reef using traditional drill-blast-scrape and narrow reef mining systems. A surface vertical shaft is used to hoist people, material and rock with a sub-incline shaft system located from 10 levels down to the end of the shaft; however, this shaft is currently being decommissioned.
- The Phakisa Shaft uses conventional scattered stopping methods to mine the basal reef at depths of up to 2 400 m;
- The Nyala Shaft is situated approximately 4 km west of Phakisa Shaft and forms a services shaft to the Phakisa Shaft. It is used for the hoisting of all ore and waste from the Phakisa workings which are hoisted halfway up the Phakisa Shaft, via an underground winder, and then transported underground to the loading and hoisting facilities at the Nyala Shaft. The Nyala Shaft is also used to dewater the Phakisa Shaft workings, as an exhaust ventilation airway and as an escape way from the Phakisa Shaft;
- The Bambanani East Shaft forms the main man and material shaft which is now not operational; whereas the Bambanani West Shaft was used for hoisting of ore and operating the backfill plant. The backfill plant has been undertaken since 2011 and an exemption in terms of GN704 has been applied for in this WULA. The backfilling consists of the mixing of tailings with cement in a binder-mixing tank and pumping it underground to backfill the mined out areas for stability;
- The Masimong 4 Shaft ceased ore production in April 2005 and has been placed under care and maintenance. It is currently only used for pumping, ventilation and as an emergency outlet; and
- The Masimong 5 Shaft is a production shaft making use of traditional drill, blast and scrape methods for the extraction of the narrow and wide reefs (Wits Reef). This shaft extends to 2 150 m below surface. All ore and waste rock from the shaft are hoisted to the surface (SRK Consulting, 2020b).

1.2.3 Joel

While the Free State Operations have been mining the Vaal Reefs since approximately 1950, the Joel Operations was only initiated during 1978. The Joel Operation's mining lease area is approximately 2 161 ha which consist of the Joel Plant and its two shafts (Joel 1 North and Joel 3 South). Joel 1 Shaft is a material shaft and hoists all ore to the surface from the underground workings; while Joel 3 Shaft is a man and material decline shaft. The associated supporting infrastructure includes the metallurgical plant, which used to process gold but is currently under care and maintenance, the TSF which is currently dormant, as well as the waste rock dumps and a sewage treatment plant.

The two shafts currently proceed with underground workings which extend to approximately 1 300 m below surface where the principal reef mined is the Beatrix Reef. This is achieved by making use of the standard open topping layout for the extraction of narrow, generally flat dipping gold reefs. All ore from the Joel Operations is processed at the Harmony One Plant and Target Plant - with Joel Mineral Processing Plant no longer operational (SRK Consulting, 2020c).

1.2.4 Saaiplaas

The Saaiplaas Operations is comprised of the Saaiplaas Plant and the Phoenix (Tswelopele) Project which has a total mining lease area of approximately 22 583 ha. This project involves the reprocessing of existing TSFs to extract gold. The operation also includes the associated supporting infrastructure of the metallurgical plant which processes gold and TSFs. Activities at the operations include:

- The re-mining of the Brand A and Dam 21 (H3);
- The re-pulped tailings from Brand A and Dam 21 (H2) being pumped to the Saaiplaas Plant; and
- Residue from the process being disposed of at the St Helena 1, 2 & 3 Slimes Dam Complex (SRK Consulting, 2020d).

1.2.5 Target

The Target Operations consists of the Target Plant and three shafts (Target 1, 2 and 3 shafts) with a total mining lease area of approximately 6 801 ha. Target 1 Shaft mines at a depth of approximately 2 500 m below ground level, producing approximately 140 000 tons of ore per annum. Target 2 Shaft is currently not operational with mining ceased in 2009. Infrastructure associated with the shaft has not been demolished as some remain in use such as the old hostels used to store core samples. Operations at Target 3 Shaft also ceased in September 2014 with the shaft under care and maintenance. Pumping of underground water continues from the shaft as it is connected via underground workings to Target 1 Shaft to maintain safe operations at Target 1 Shaft. The associated supporting infrastructure includes the metallurgical plant which processes gold, the TSF, waste rock dumps and sewage treatment plant. The Target Metallurgical Plant is situated south of Target 1 Shaft, which processes ore from the Target 1 shaft including add up with waste rock material from the associated waste rock dumps at the shafts (SRK Consulting, 2020e).

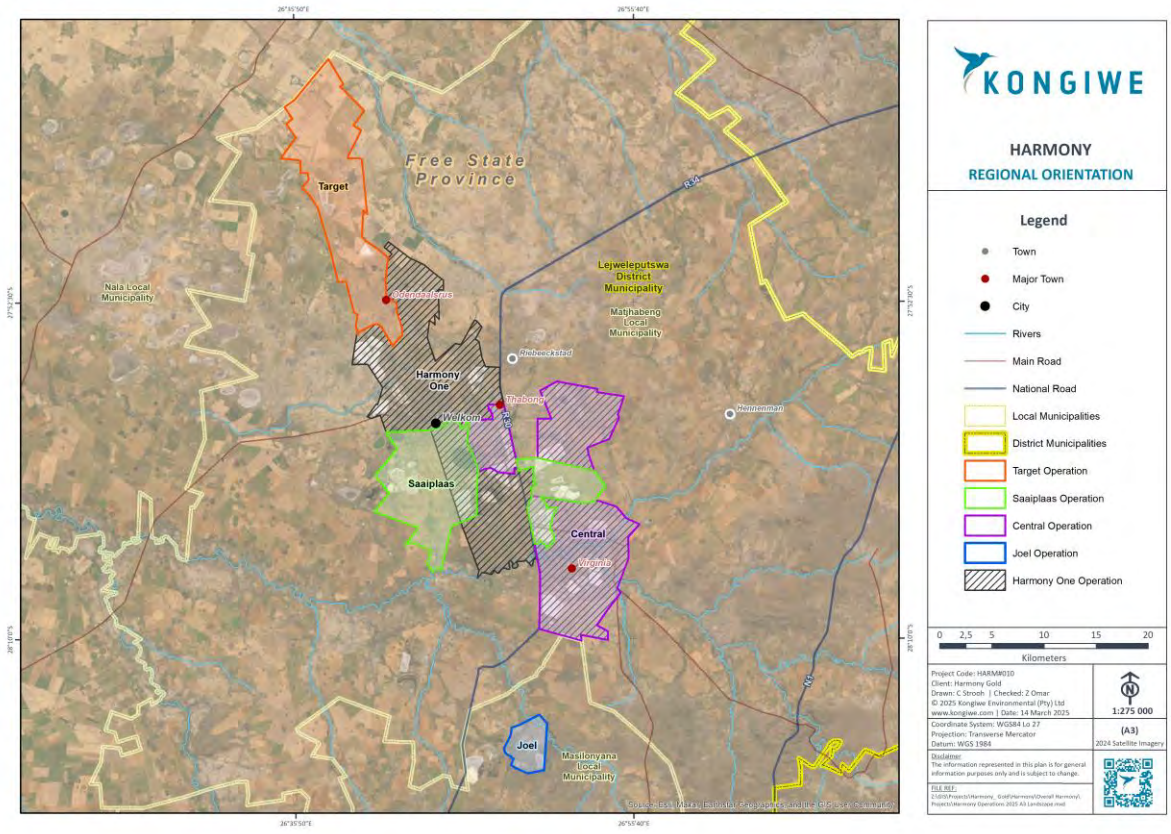


Figure 1-1: Separate boundaries for each of the five water use operational areas at Harmony Free State Operations

2 Project Area

The Harmony Free State Operations surrounds the town of Welkom and extends to both the north direction, at the Target Operations to Allanridge, and south towards Virginia at the Harmony One Operations. Operations border one another with the only exception of Joel Mine which is separated by Sibanye Stillwater's Beatrix Operations from the main cluster of Mines. These operations therefore are located within the Matjhabeng Local Municipality with Joel Mine located in the Masilonyana Local Municipality of the greater Lejweleputswa District Municipality, Free State province, South Africa (Figure 2-1).

2.1 Hydrological Setting

The hydrological setting of the project area is presented in Figure 2-2. The Harmony Free State Operations are situated in the C25B, C25F, C42J, C42L, C42H, C42K and C43B quaternary catchments, within the Vaal Water Management Area (WMA-1) (NWA, 2016). The operations cross the C25B – 02400, C25B – 02423 - C43B – 02577, C42J – 02590, C42J – 02716, C42H – 02745, C42J – 02578 and C42K - 02754 SQRs along with multiple tributaries of these systems in the Highveld Lower– Aquatic Ecoregion.

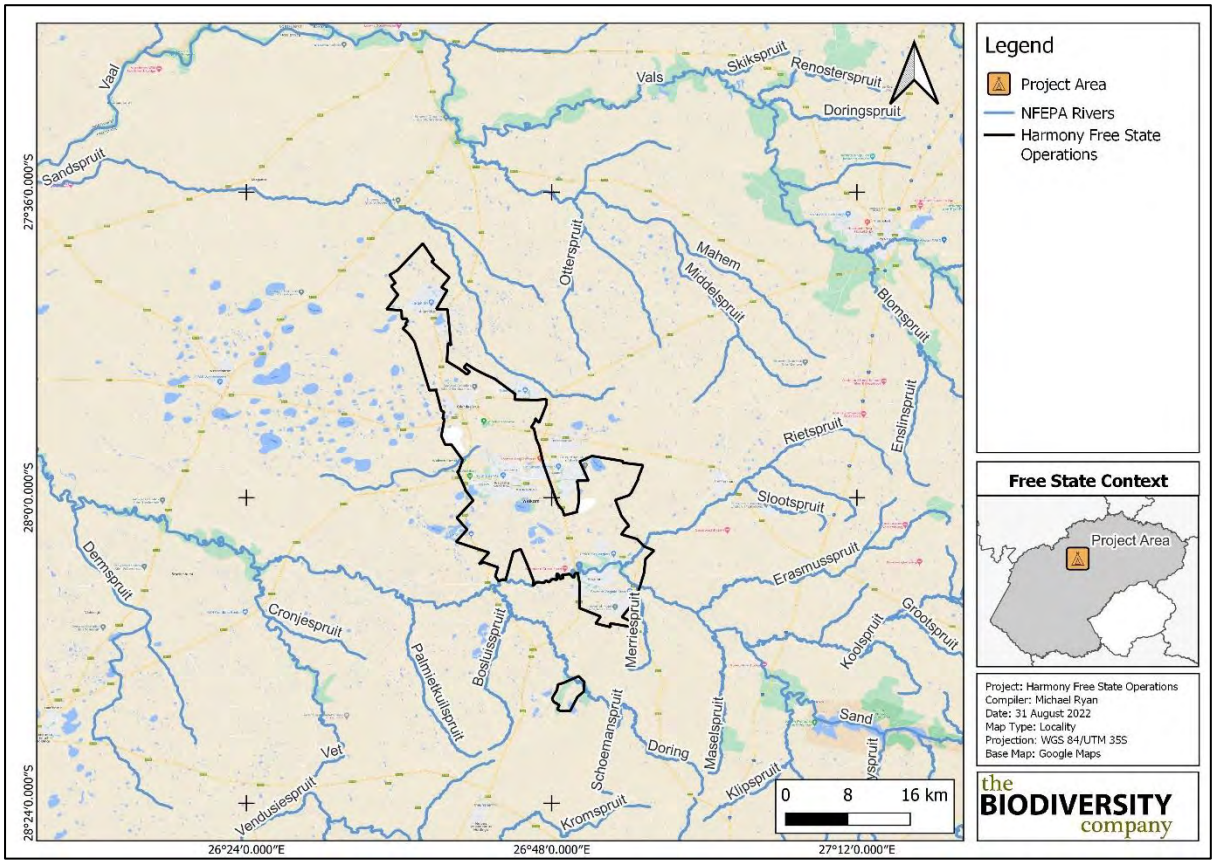


Figure 2-1: Locality map illustrating the Harmony Free State Operations

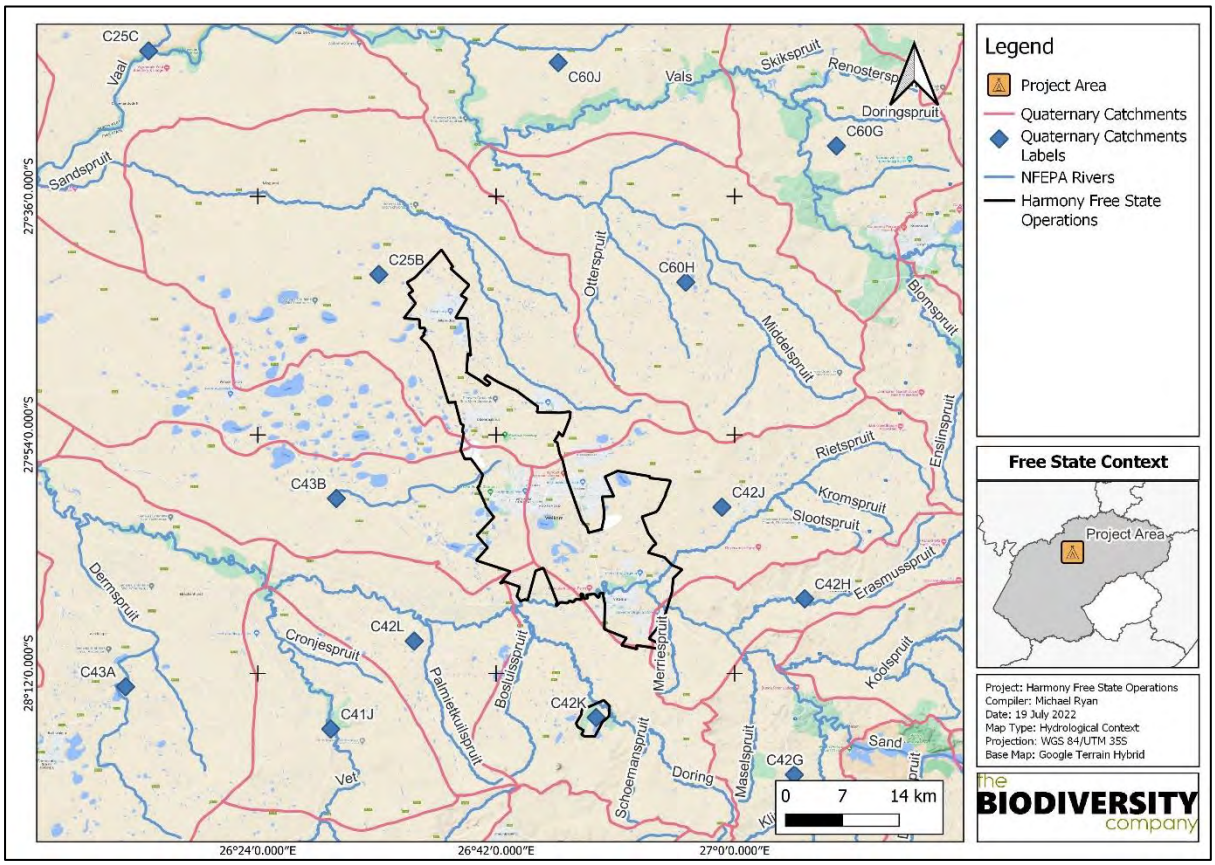


Figure 2-2: Hydrological context of the project area

2.2 Site Selection

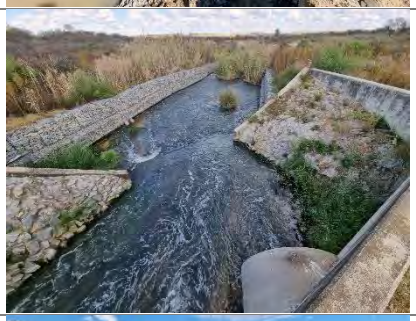
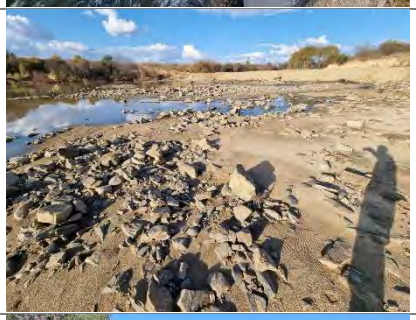
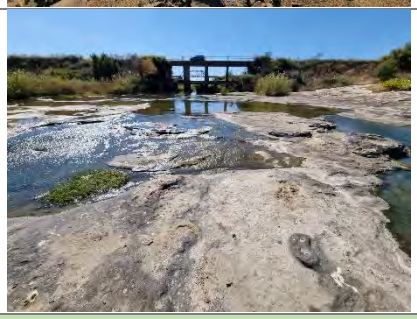
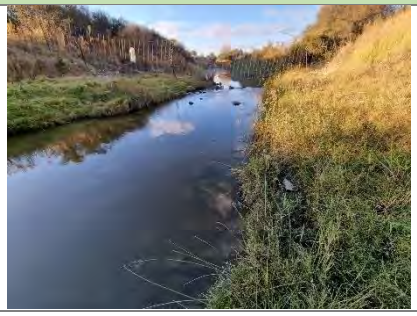
The sampling points for the study were selected to assess adequately the current state of the relevant watercourses within the project area of the Harmony Free State Operations to identify the potential or current risks that may result from the operational or decommissioned mining activities and the associated infrastructure of any of the five operational divisions of the Harmony Free State. This was done to gain a holistic image of the systems and which habitats which may be or currently are being affected.

To achieve this, sites were selected by first consulting the Integrated Water and Waste Management Plan (IWWMP) established by SRK Consulting (2020a-2020e) for all five operations to correlate sites and site labels for the ease of readers interpreting the presented data. The volume of sites presented in the five documents were considered exhaustive for the purposes of the aquatic assessment and therefore multiple points were removed. Most removed sampling points were isolated waterbodies which constitute part of the scope of surface water monitoring with only water quality sites which may potentially affect the water quality of the watercourses of the project area assessed. These sites should continue to be monitored under the surface water monitoring programme with results integrated into the biomonitoring programme to provide insight.

The selected sampling locations were divided per operation; however, multiple sites are considered relevant to multiple operations due to the proximity of the operations to one another as they share boundaries. The selected sampling locations as well as photographs and Global Positioning Points (GPS) are presented in: Table 2-1 and Figure 2-3 for the Central Operations; Table 2-2 and Figure 2-4 for the Harmony One Operations; Table 2-3 and Figure 2-5 for the Joel Operations; Table 2-4 and Figure 2-6 for the Saaiplaas Operations; as well as Table 2-5 and Figure 2-7 for the Target Operations. The tables present upstream and downstream photograph of all watercourses and a single photograph of dams. They are presented in a downstream direction according to each river reach.

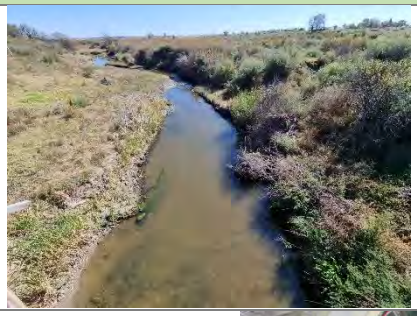
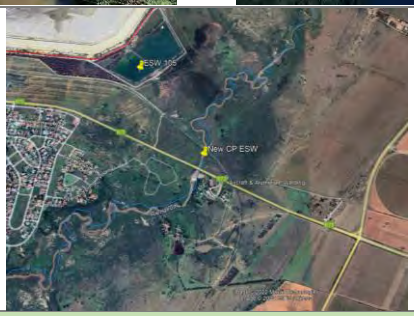
Table 2-1: Photos, co-ordinates and descriptions for the sites sampled for Central Operations (May 2022)

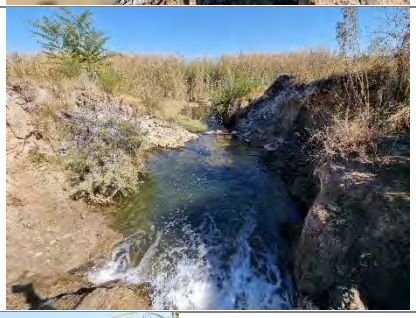
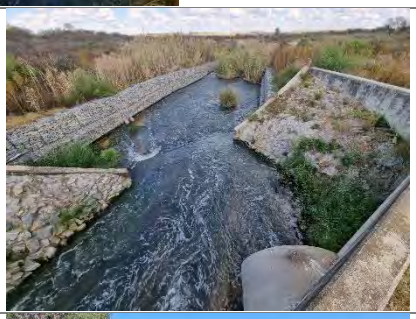
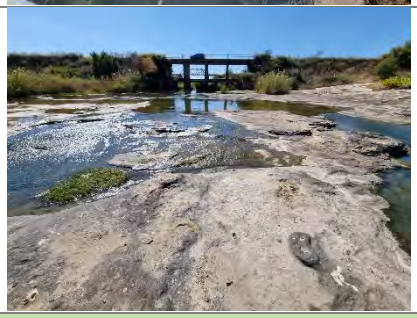
Site	Upstream	Downstream	GPS coordinates
Rietspruit River			
New CP ESW			28° 4'53.92"S 26°54'24.58"E
Merriespruit			
SVC 14			28°10'33.54"S 26°55'22.03"E

Sand River			
SVC 01			28° 6'50.98"S 26°54'36.53"E
SVC 10/ Moster t canal 12/ ESW 54			28° 5'35.89"S 26°48'20.81"E
SVC 11			28° 6'21.41"S 26°48'39.84"E
SVC 08			28° 7'3.07"S 26°43'9.79"E
Doring River			
SVC 05			28°11'17.94"S 26°47'54.00"E
ESW TK1	No Access		28° 9'48.47"S 26°49'3.71"E

Site	Upstream	Downstream	GPS coordinates
Doring River			
SVC 7			28° 8'4.65"S 26°44'10.23"E
Bosluisspruit River			
SVC 6			28° 9'20.72"S 26°44'39.74"E

Table 2-2: Photos, co-ordinates and descriptions for the sites sampled for Harmony One Operations (May 2022)

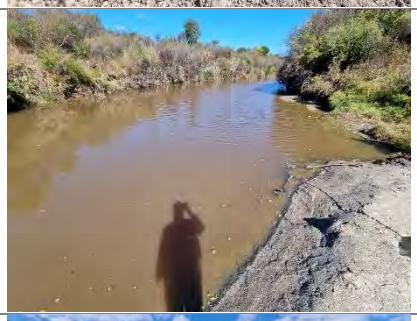
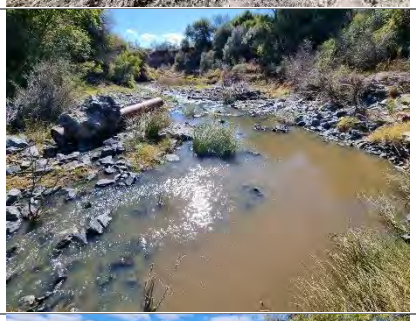
Site	Upstream	Downstream	GPS coordinates
Rietspruit River			
SVC 3			28° 2'42.47"S 26°57'27.22"E
New CP ESW			28° 4'53.92"S 26°54'24.58"E
Sand River			

Site	Upstream	Downstream	GPS coordinates
SVC 01			28° 6'50.98"S 26°54'36.53"E
ESW 85			28° 7'0.93"S 26°51'23.32"E
ESW 55			27°57'42.71"S 26°48'55.44"E
SVC 10/Mostert 12/ ESW 54			28° 5'35.89"S 26°48'20.81"E
SVC 08			28° 7'3.07"S 26°43'9.79"E
Mahem River			

Site	Upstream	Downstream	GPS coordinates
ESW 17			27°56'1.54"S 26°42'6.58"E
ESW 14			27°57'13.32"S 26°40'38.00"E
Mahem 4B	No Access		27°58'19.56"S 26°38'52.22"E
ESW 100			28° 2'31.86"S 26°39'11.09"E
Sandspruit River			
SVC 15			27°51'59.71"S 26°48'5.75"E
SVC 16			27°48'36.86"S 26°42'53.60"E

Site	Upstream	Downstream	GPS coordinates
ESW 6			27°50'43.11"S 26°39'20.19"E

Table 2-3: Photos, co-ordinates and descriptions for the sites sampled for Joel Operations (May 2022)

Site	Upstream	Downstream	GPS coordinates
Doring			
SVC12	No Access		28°16'12.37"S 26°53'44.32"E
ESW 71			28°17'18.64"S 26°49'55.07"E
ESW 82			28°14'47.10"S 26°50'38.30"E
ESW 65			28°14'5.45"S 26°50'53.06"E
SVC 04			28°13'55.06"S 26°49'13.07"E

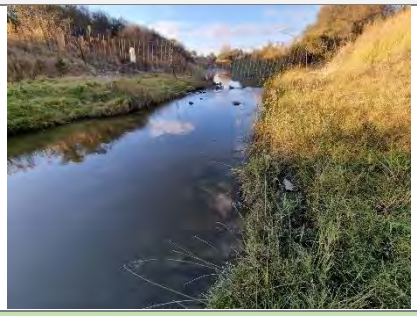
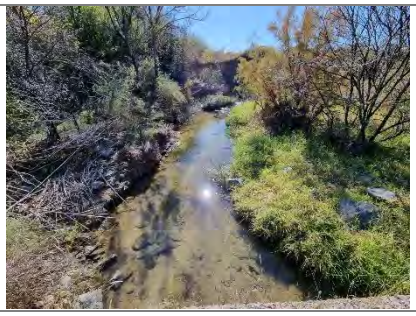
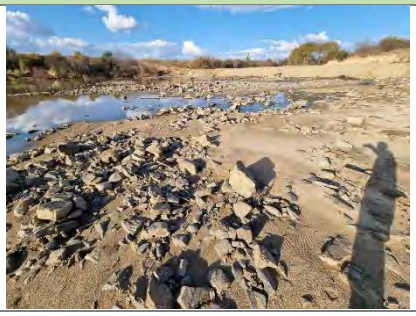
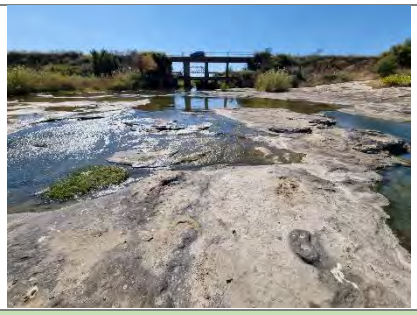
Site	Upstream	Downstream	GPS coordinates
SVC05			28°11'17.94"S 26°47'54.00"E
Theronspruit River			
ESW 79	No Access		28°16'43.39"S 26°48'15.90"E
ESW 80			28°15'55.00"S 26°48'30.60"E

Table 2-4: Photos, co-ordinates and descriptions for the sites sampled for Saaiplaas Operations (May 2022)

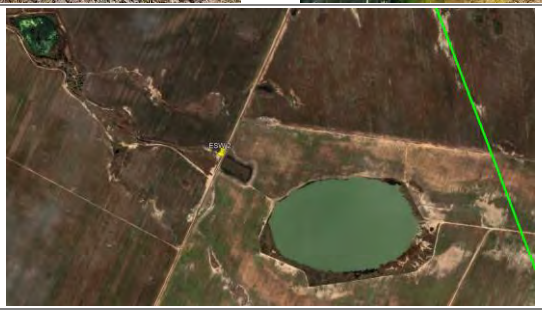
Site	Upstream	Downstream	GPS coordinates
Rietspruit River			
SVC 03			28° 2'42.47"S 26°57'27.22"E
Sand River			
SVC 11			28° 6'21.41"S 26°48'39.84"E

Site	Upstream	Downstream	GPS coordinates
ESW 98			28° 5'40.09"S 26°44'5.22"E
ESW 99	No Access		28° 6'18.73"S 26°44'30.05"E
SVC 08			28° 7'3.07"S 26°43'9.79"E
Doring River			
SVC 07			28° 8'4.65"S 26°44'10.23"E
Mahem River			
ESW 73			28° 2'16.27"S 26°39'54.20"E
ESW 101			28° 3'25.02"S 26°40'24.47"E

Site	Upstream	Downstream	GPS coordinates
ESW 100			28° 2'31.86"S 26°39'11.09"E

Table 2-5: Photos, co-ordinates and descriptions for the sites sampled for Target Operations (May 2022)

Site	Upstream	Downstream	GPS coordinates
Sandspruit River			
SVC 15			27°51'59.71"S 26°48'5.75"E
SVC 16			27°48'36.86"S 26°42'53.60"E
SVC 17			27°37'43.13"S 26°37'56.81"E
Losdoringspruit			
EWS 6			27°50'43.11"S 26°39'20.19"E

Site	Upstream	Downstream	GPS coordinates
ESW 1			27°48'25.22"S 26°35'54.21"E
ESW 2			27°50'59.60"S 26°37'28.87"E

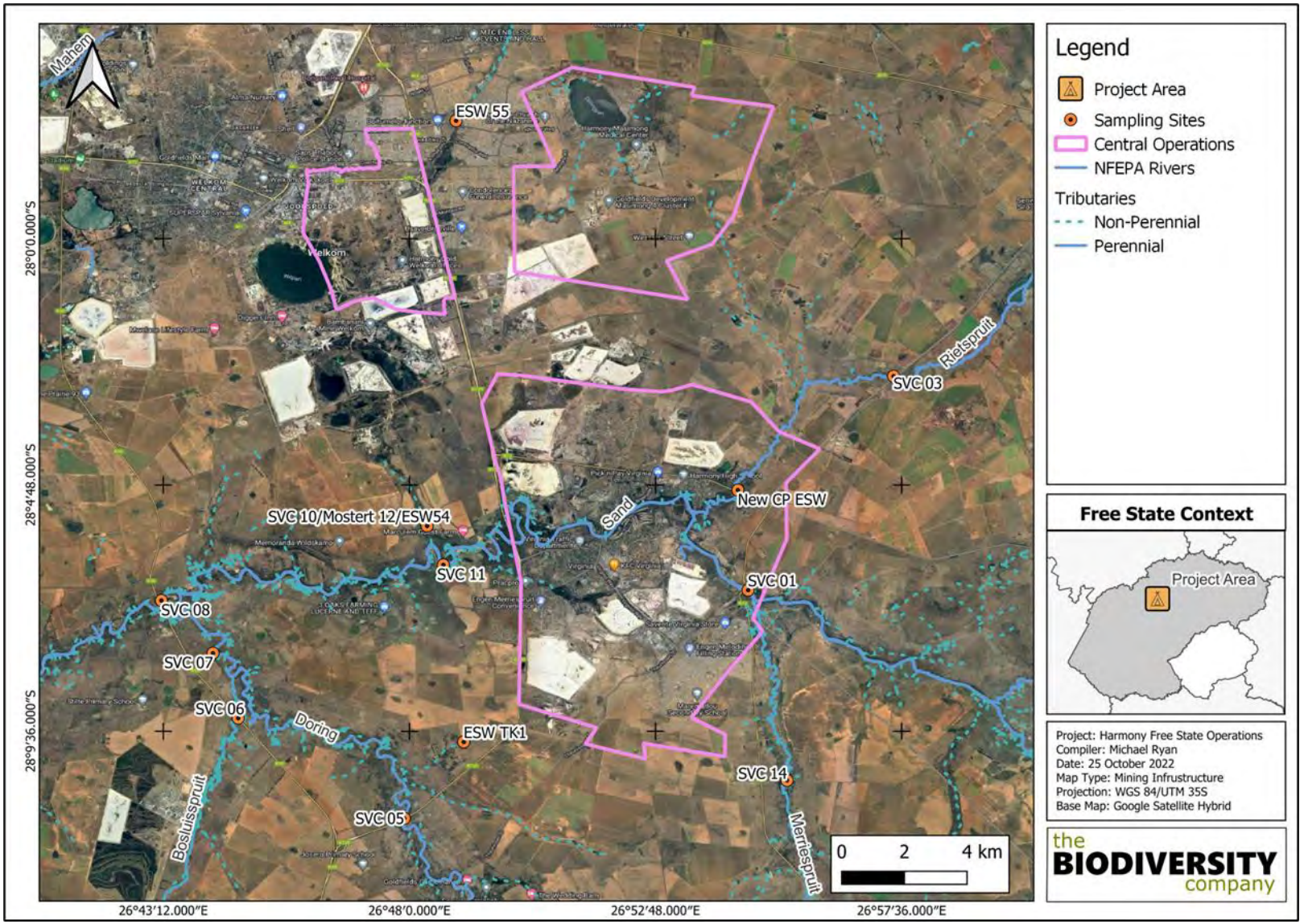


Figure 2-3: Illustration of Central Operations sampling points

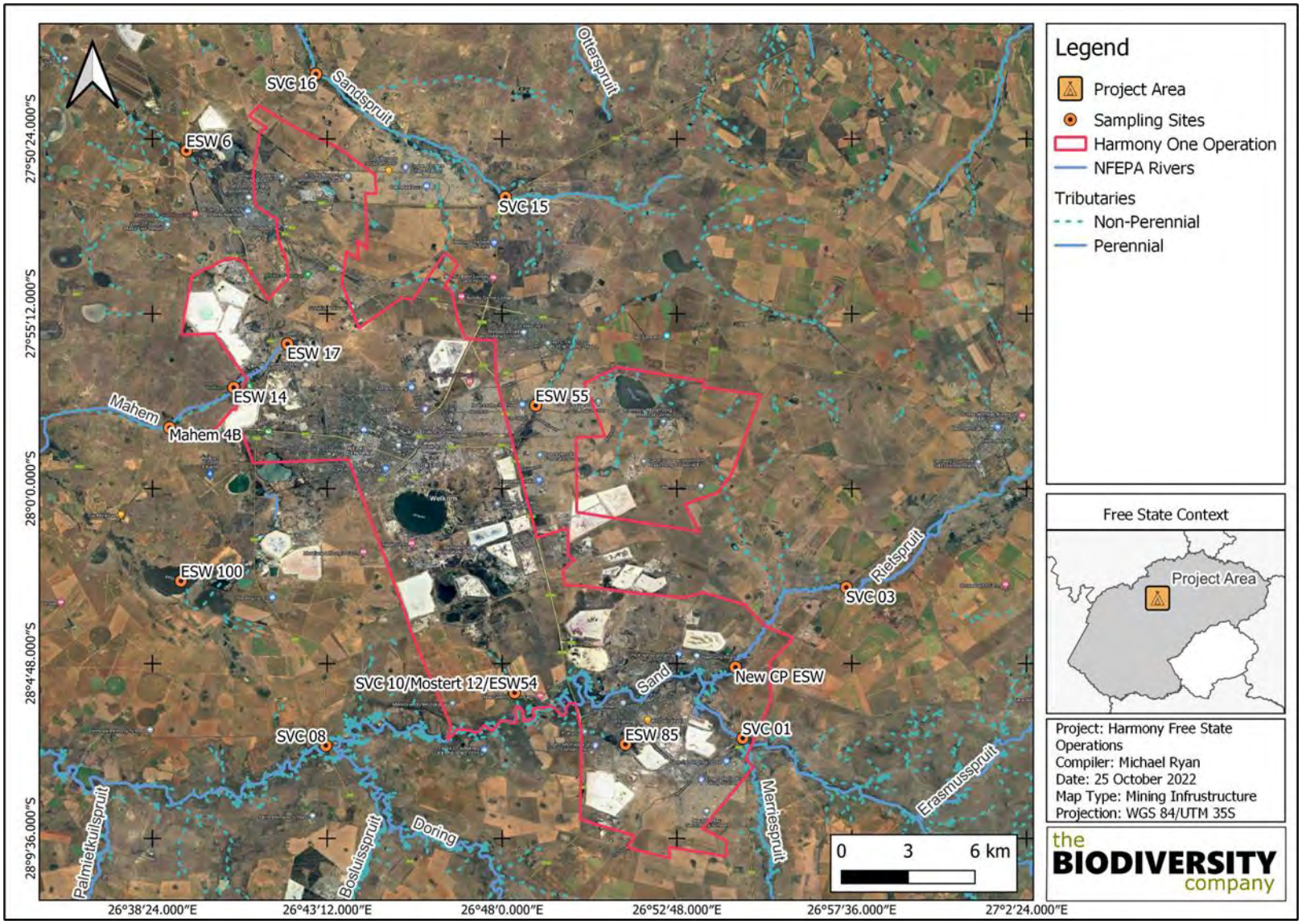


Figure 2-4: Illustration of Harmony One Operations sampling points

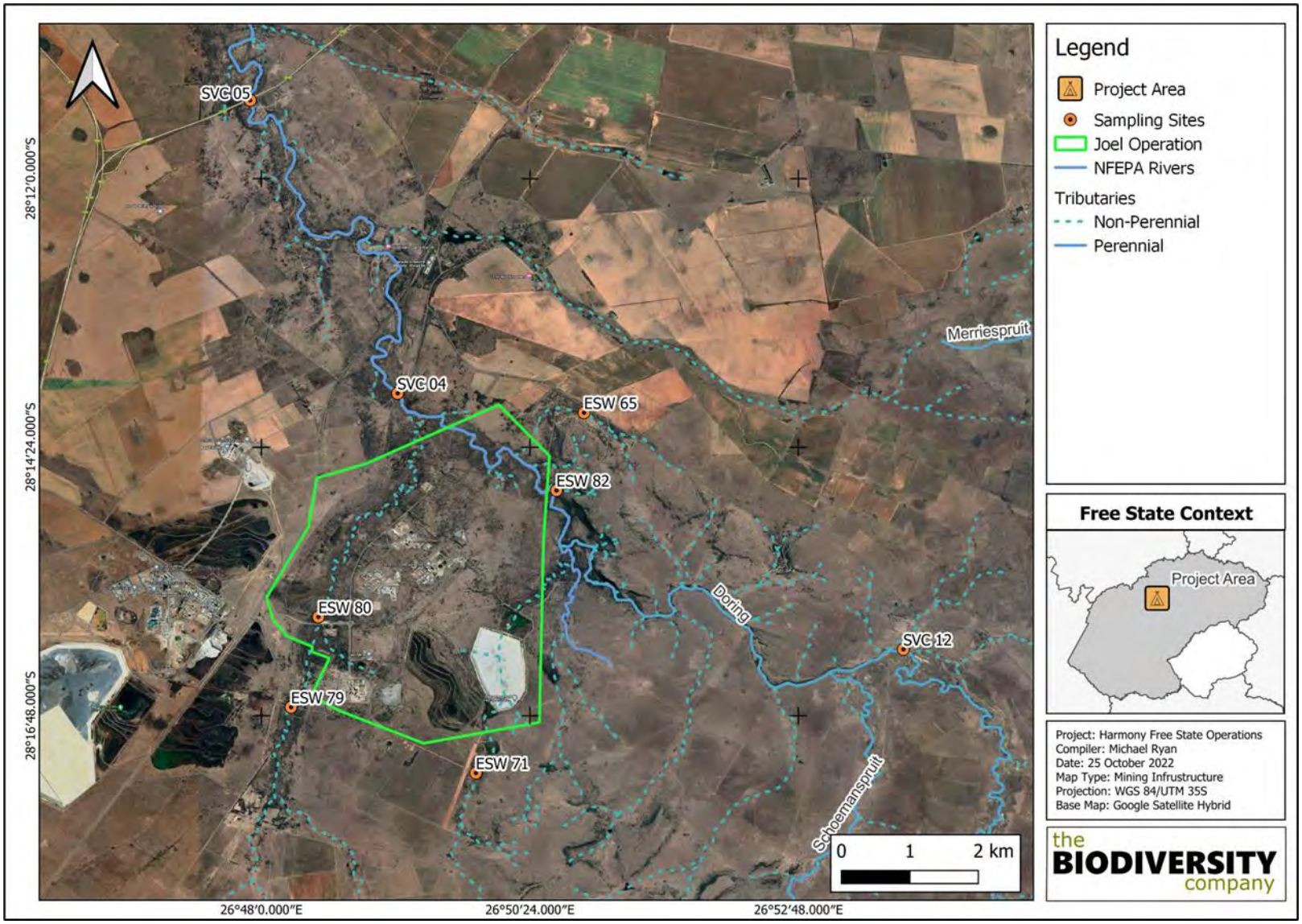


Figure 2-5:Illustration of Joel Operations sampling points

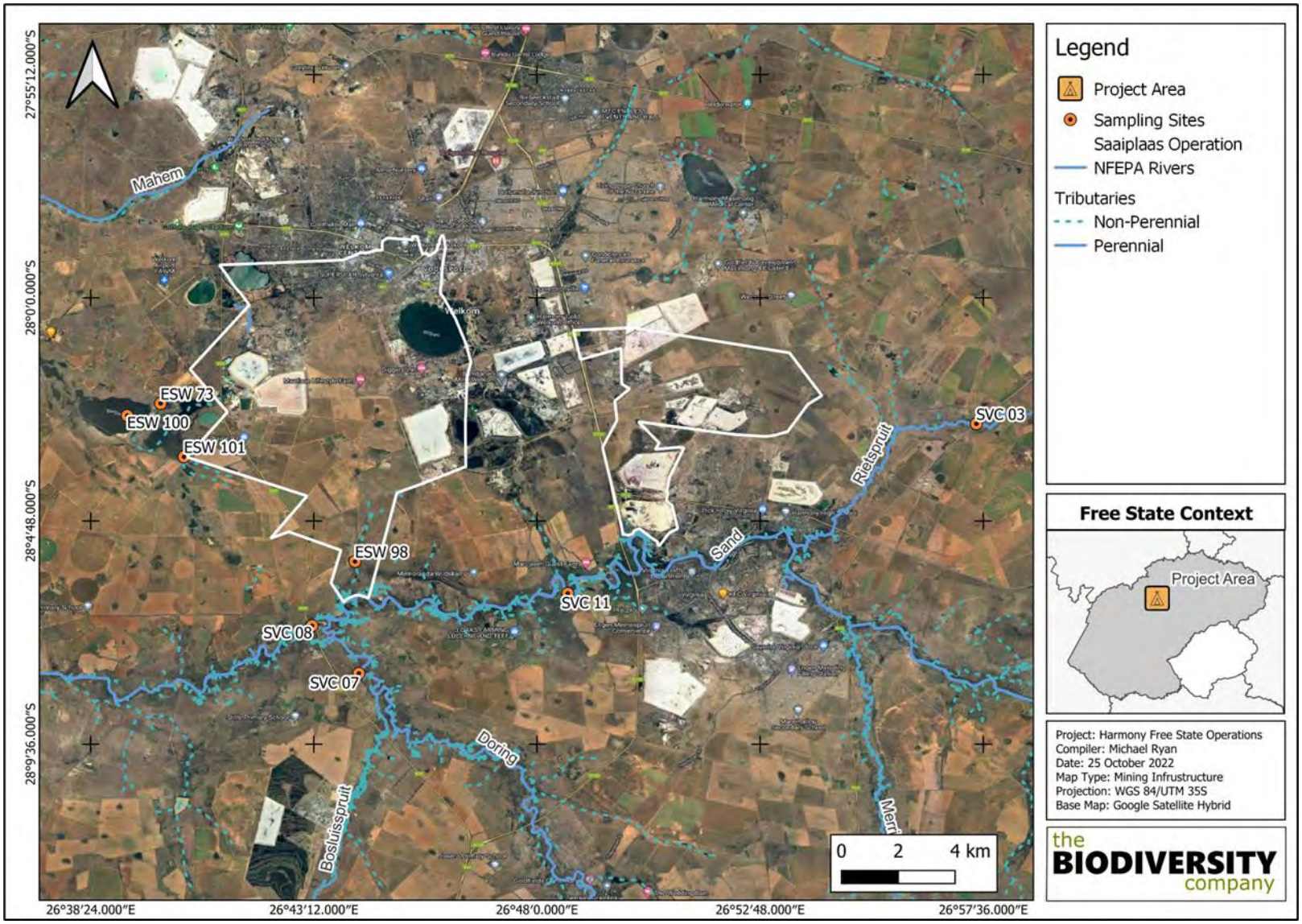


Figure 2-6: Illustration of Saaiplaas Operations sampling points

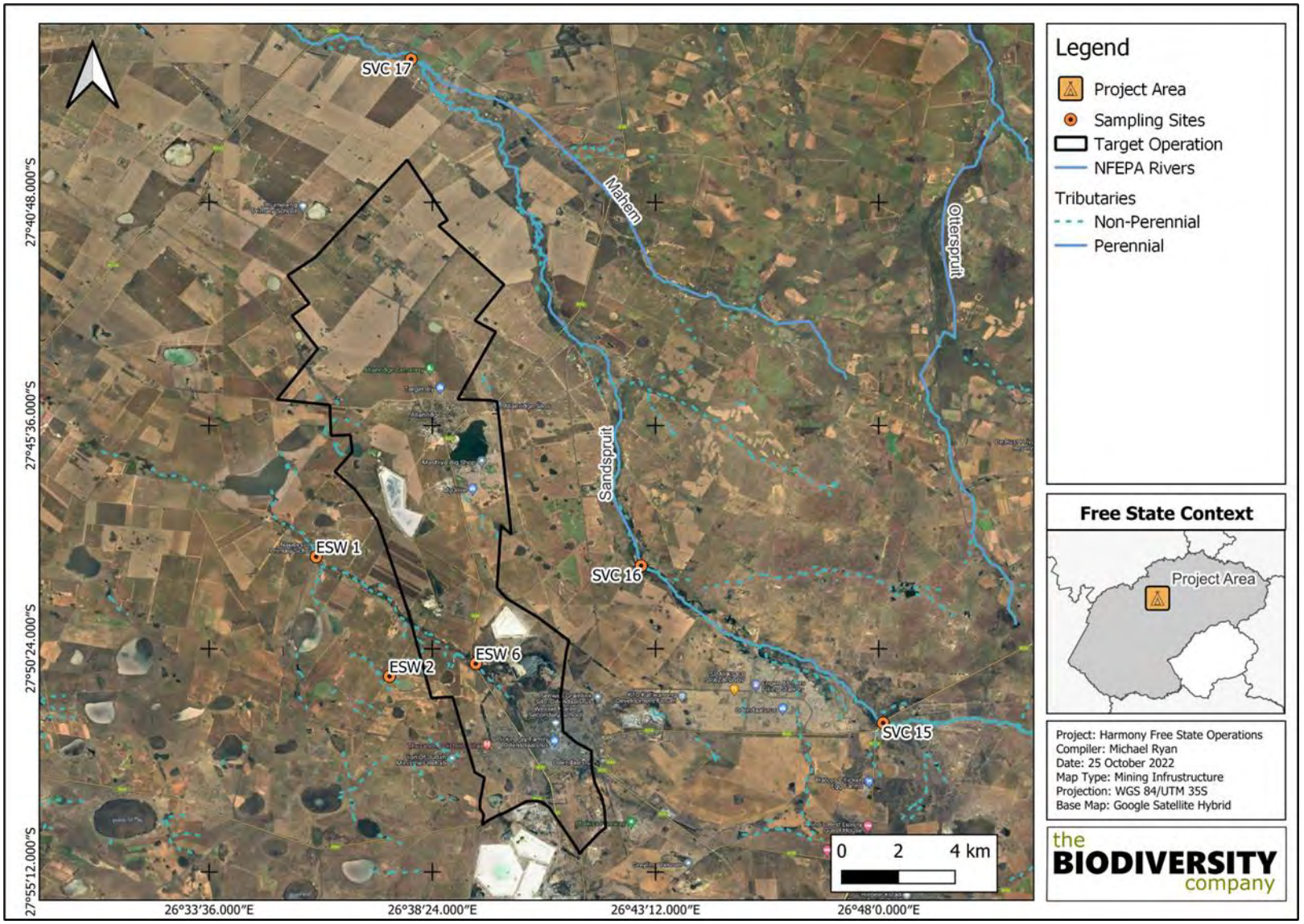


Figure 2-7: Illustration of Target Operations sampling point

3 Desktop Assessment

3.1 National Freshwater Ecosystem Priority Areas (NFEPA)

The National Freshwater Ecosystem Priority Areas (NFEPA) database forms part of a comprehensive approach to the sustainable and equitable development of South Africa's scarce water resources. This database provides guidance on how many rivers, wetlands and estuaries, and which ones, should remain in a natural or near-natural condition to support the water resource protection goals of the NWA. These NFEPAs directly apply to the NWA as they are used to establish Catchment Management Strategies, water resource classification and reserve determination, as well as the setting and monitoring of resource quality objectives (Nel *et al*., 2011). The NFEPAs are intended to be conservation support tools and envisioned to guide the effective implementation of measures to achieve the biodiversity goals of the National Environment Management: Biodiversity Act, 2004 (Act No 10 of 2004) (NEM:BA), informing both the listing of threatened freshwater ecosystems and the process of bioregional planning provided for by this Act (Nel *et al.,* 2011).

The Harmony Free State Operations cross the boundaries of 10 separate Sub-quaternary catchments (SQC) namely: 2337, 2423, 2517, 2577, 2578, 2590, 2690, 2716, 2745 and 2754 SQCs (Figure 3-1). All these catchments are considered SQCs with no assigned sensitivity from a NFEPA context, with SQCs 2337, 2423, 2517, 2577, and 2754 considered sensitive due to the presence of multiple wetland clusters and multiple NFEPA wetlands as presented in Table 3-1. These represent predominantly natural wetland systems however may include naturalised artificial systems. The extensive footprint of the Harmony Free State Operations accounts for the multiple SQCs and wetland systems traversed within its boundaries. Activities within the Harmony Free State Operations do not however extend throughout their boundaries. To identify whether any activities have the potential to impact any wetland system, a more extensive study is required and does not fall within the scope of this report.

Table 3-1: The NFEPA categories of the relevant catchments

Type of FEPA map category	Biodiversity features	Type of FEPA map category	Biodiversity features
Sub-quaternary catchment 2337		Sub-quaternary catchment 2423	
FEPA: Number of wetland clusters	9 WetCluster FEPAs	FEPA: Number of wetland clusters	4 WetCluster FEPAs
FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Channelled valley-bottom wetland	FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Channelled valley-bottom wetland
FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Depression	FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Depression
FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Flat	FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Flat
FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Seep	FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Seep
FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Unchannelled valley-bottom wetland	FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Unchannelled valley-bottom wetland
FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Valleyhead seep	FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Valleyhead seep
FEPA: Wetland ecosystem type	Eastern Kalahari Bushveld Group 3_Depression		
Sub-quaternary catchment 2517		Sub-quaternary catchment 2577	
FEPA: Number of wetland clusters	2 WetCluster FEPAs	FEPA: Number of wetland clusters	4 WetCluster FEPAs
FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Channelled valley-bottom wetland	FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Channelled valley-bottom wetland
FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Depression	FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Depression
FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Flat	FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Flat

Type of FEPA map category	Biodiversity features	Type of FEPA map category	Biodiversity features
FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Seep	FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Floodplain wetland
FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Unchannelled valley-bottom wetland	FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Seep
FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Valleyhead seep	FEPA: Wetland ecosystem type	Dry Highveld Grassland Group 3_Valleyhead seep
FEPA: Wetland ecosystem type	Eastern Kalahari Bushveld Group 3_Depression	FEPA: Wetland ecosystem type	Eastern Kalahari Bushveld Group 3_Depression
Sub-quaternary catchment 2578		Sub-quaternary catchment 2590	
None		None	
Sub-quaternary catchment 2690		Sub-quaternary catchment 2716	
None		None	
Sub-quaternary catchment 2745			
None			
Sub-quaternary catchment 2754			
FEPA: Number of wetland clusters		3 WetCluster FEPAs	
FEPA: Wetland ecosystem type		Dry Highveld Grassland Group 3_Channelled valley-bottom wetland	
FEPA: Wetland ecosystem type		Dry Highveld Grassland Group 3_Depression	
FEPA: Wetland ecosystem type		Dry Highveld Grassland Group 3_Flat	
FEPA: Wetland ecosystem type		Dry Highveld Grassland Group 3_Seep	
FEPA: Wetland ecosystem type		Dry Highveld Grassland Group 3_Unchannelled valley-bottom wetland	
FEPA: Wetland ecosystem type		Dry Highveld Grassland Group 4_Channelled valley-bottom wetland	
FEPA: Wetland ecosystem type		Dry Highveld Grassland Group 4_Flat	
FEPA: Wetland ecosystem type		Dry Highveld Grassland Group 4_Seep	
FEPA: Wetland ecosystem type		Dry Highveld Grassland Group 4_Unchannelled valley-bottom wetland	
FEPA: Wetland ecosystem type		Dry Highveld Grassland Group 4_Valleyhead seep	

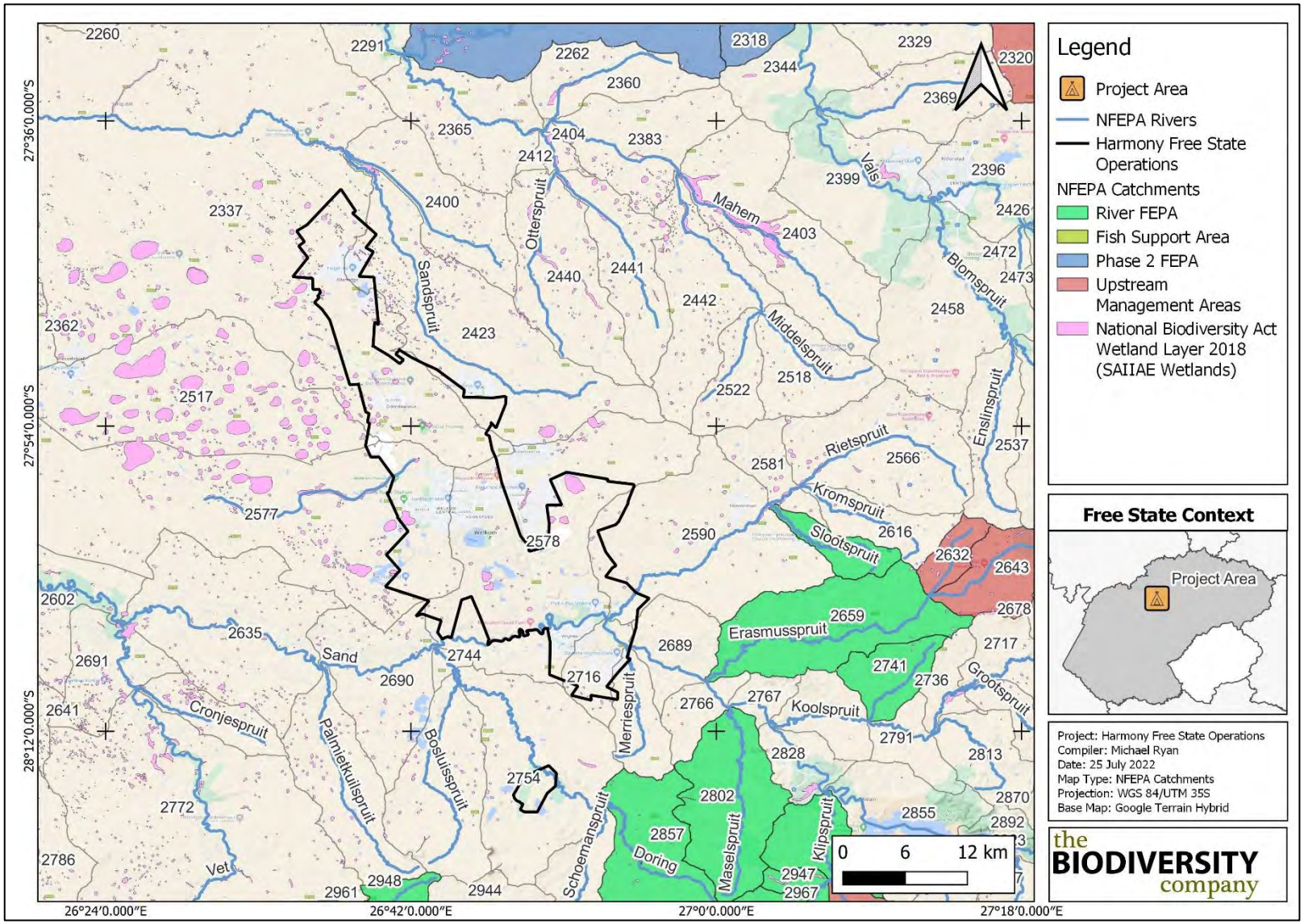


Figure 3-1: Layout of the Harmony Free State Operations in relation to the riverine National Freshwater Priority Areas

3.2 National Wetland Map 5

The National Wetland Map 5 (NWM5) spatial data was published in October 2019 (Deventer *et al*. 2019), in collaboration with the South African National Biodiversity Institute (SANBI), with the specific aim of spatially representing the location, type and extent of wetlands in South Africa. The data represents a synthesis of a wide number of official watercourse data including rivers, inland wetlands, and estuaries. This database does recognise the presence of wetlands within the extent of the project area (Figure 3-2). These coincide with the listed wetlands identified in section 3.1. The wetlands systems which are within the Harmony Free State Operations include both depressions and seeps from the Dry Highveld Grassland Group 3 ecosystem type. Despite wetlands not being the focus of the assessment, they are also considered watercourses with these systems working with rivers to provide multiple ecosystem services.

Due to the sensitive habitat of the associated wetlands, concern should be given to available habitat within the project area as activities may have impacts on all systems downstream of the project area. Typically, wetlands offer a host of ecosystems services such as the purification of water quality through phytoremediation by the wetland vegetation. The wetlands are expected to provide cleansing effects from surface runoff associated with the Harmony Free State Operations and other surrounding land uses such as agriculture and sewage treatment works. Therefore, they must be maintained and protected for the valuable ecosystem services that they provide.

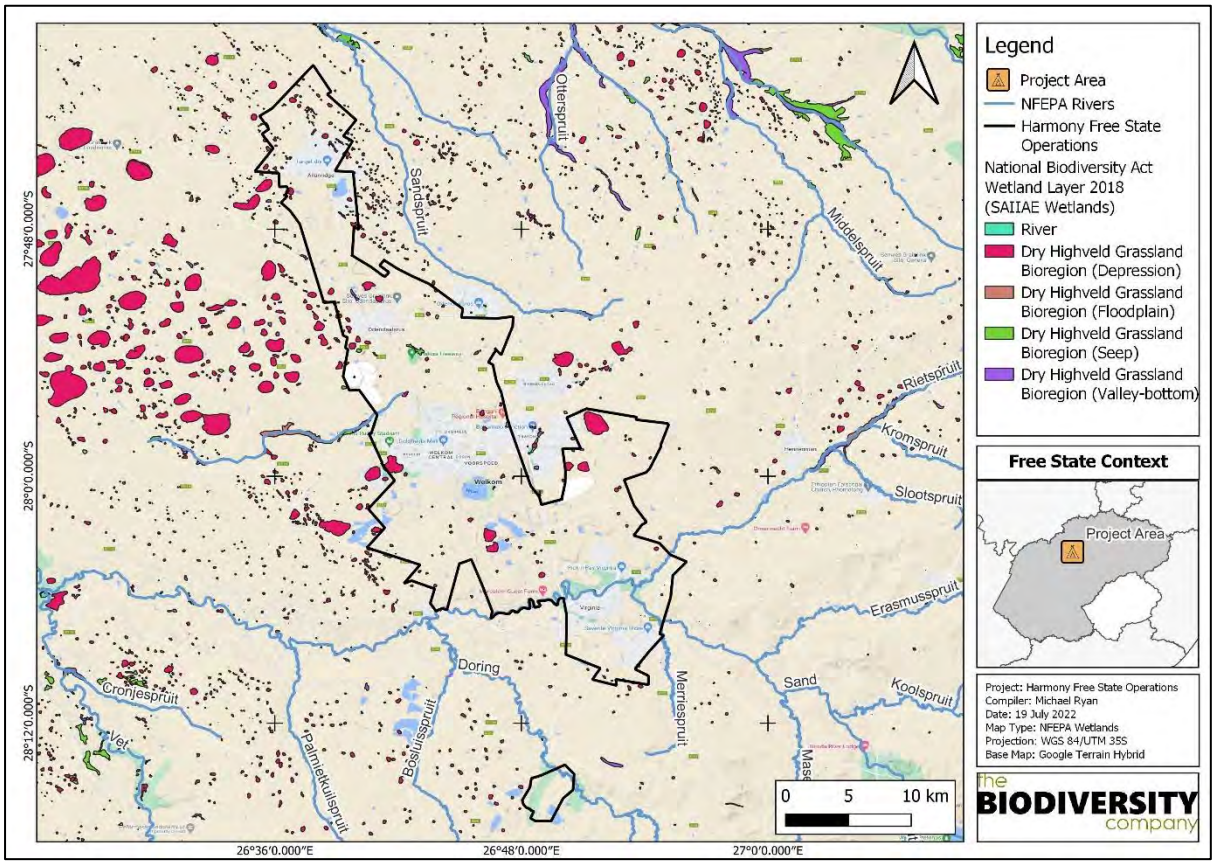


Figure 3-2: NFEPA wetlands present within the project area

3.3 Status of Sub-Quaternary Reach's

Desktop information for all SQRs relevant to the project area was obtained from the Department of Water and Sanitation (DWS, 2014). Eight separate SQRs were identified for the project area and are presented in Table 3-2. The Desktop PES of these systems is presented in Figure 3-3. The desktop PES category of the C42K - 02754 SQR (Doring River) was classed as largely natural (class B); the C42H – 02745 SQR (Merriespruit River); C25B – 02423 SQR (Sandspruit River) and C25B – 02400

SQR (Unnamed River) was classed as moderately modified (class C); while the C42J – 02716 SQR (Sand River) and C42J - 02590 SQR (Rietspruit River) was classed as largely modified (class D); while the PES category of the C42J – 02578 SQR (Sand River) and C43B – 02577 SQR (Mahem River) was classed as seriously modified (class E). The state of these reaches is based on impacts to instream habitat, as well as wetland and riparian zone continuity, flow modifications, and moderate potential impacts on physico-chemical conditions (water quality). These are discussed further in Table 3-2.

Table 3-2: Summary of the Present Ecological State of the SQRs associated with the Harmony Free State Operations (DWS, 2014)-

SQR	Stream order	Length (km)	PES (DWS, 2014)	Ecological Sensitivity (ES)	Ecological Importance (EI)	Default Ecological Category
Sandspruit River						
C25B – 02400	1	21.66	Moderately Modified (class C)	Moderate	Moderate	C
PES-EIS Justification		Moderate impacts to instream habitat and connectivity. Large water quality perturbations and small flow modifications. High to very high instream and wetland integrity class. Moderate to high sensitivity of aquatic biota to changes in flow and physicochemical modifications. Impacts within the reach are attributed to roads, instream weirs and dams, surrounding agriculture and irrigation at bottom of the reach from Vaal				
C25B – 02423	1	46.65	Moderately Modified (class C)	Moderate	Moderate	C
PES-EIS Justification		Small impacts to instream habitat and connectivity. Large water quality perturbations and small flow modifications. Moderate to high instream and wetland integrity class. Moderate to high sensitivity of aquatic biota to changes in flow and physicochemical modifications. Impacts to the system result from roads, settlement, Waste Water Treatment Works (WWTWs) and surrounding agriculture.				
Mahem River						
C43B – 02577	1	25.16	Seriously Modified (class E)	Moderate	Moderate	C
PES-EIS Justification		Large impacts to instream habitat and connectivity. Serious water quality perturbations and serious flow modifications. Low to moderate instream and wetland integrity class. Impacts are largely unassessed due to serious impacts which have resulted from the lack of connection to the main stem river.				
Rietspruit River						
C42J - 02590	2	26.88	Largely Modified (class D)	Moderate	Moderate	C
PES-EIS Justification		Moderate impacts to instream habitat and connectivity. Large water quality perturbations and moderate flow modifications. Very low to moderate instream and wetland integrity class. High to very high sensitivity of aquatic biota to changes in flow and physicochemical modifications. Impacts within the reach are attributed to roads, instream dams, urban runoff from the town of Henneman, small holdings and Virginia at bottom reach, water purification works and surrounding agriculture				
Sand River						
C42J – 02716	3	4.52	Largely Modified (class D)	Moderate	High	B
PES-EIS Justification		Moderate impacts to instream habitat and connectivity. Serious water quality perturbations and moderate flow modifications. Very low to high instream and wetland integrity class. Moderate to high sensitivity of aquatic biota to changes in flow and physicochemical modifications. Impacts to the system include urban runoff from the town of Virginia, mining, multiple instream dams and alien invasive plants established in riparian areas.				
C42J – 02578	3	27.67	Seriously Modified (class E)	Moderate	Moderate	C
PES-EIS Justification		Large impacts to instream habitat and connectivity. Serious water quality perturbations and large flow modifications. Low to moderate instream and wetland integrity class. Moderate to high				

		sensitivity of aquatic biota to changes in flow and physicochemical modifications. Impacts include urban runoff from Virginia, mining, roads and instream dams, WWTW, and slimes dams.				
Merriespruit River						
C42H – 02745	1	19.10	Moderately Modified (class C)	Moderate	Moderate	C
PES-EIS Justification		Moderate impacts to instream habitat and connectivity. Large water quality perturbations and small flow modifications. Very low to moderate instream and wetland integrity class. Low to moderate sensitivity of aquatic biota to changes in flow and physicochemical modifications. Impacts in the reach result from instream dams, urban runoff from Virginia and surrounding townships, roads, and old lands				
Doring River						
C42K - 02754	2	32.57	Largely Natural (class B)	High	Moderate	B
PES-EIS Justification		Minor impacts to instream habitat and connectivity, water quality and flow modifications are small. Very high instream and wetland integrity class and connectivity. Moderate to High sensitivity of aquatic biota to changes in flow and physicochemical modifications. Impacts within the reach are attributed to mining, slimes dams, agriculture, small dams, and roads.				

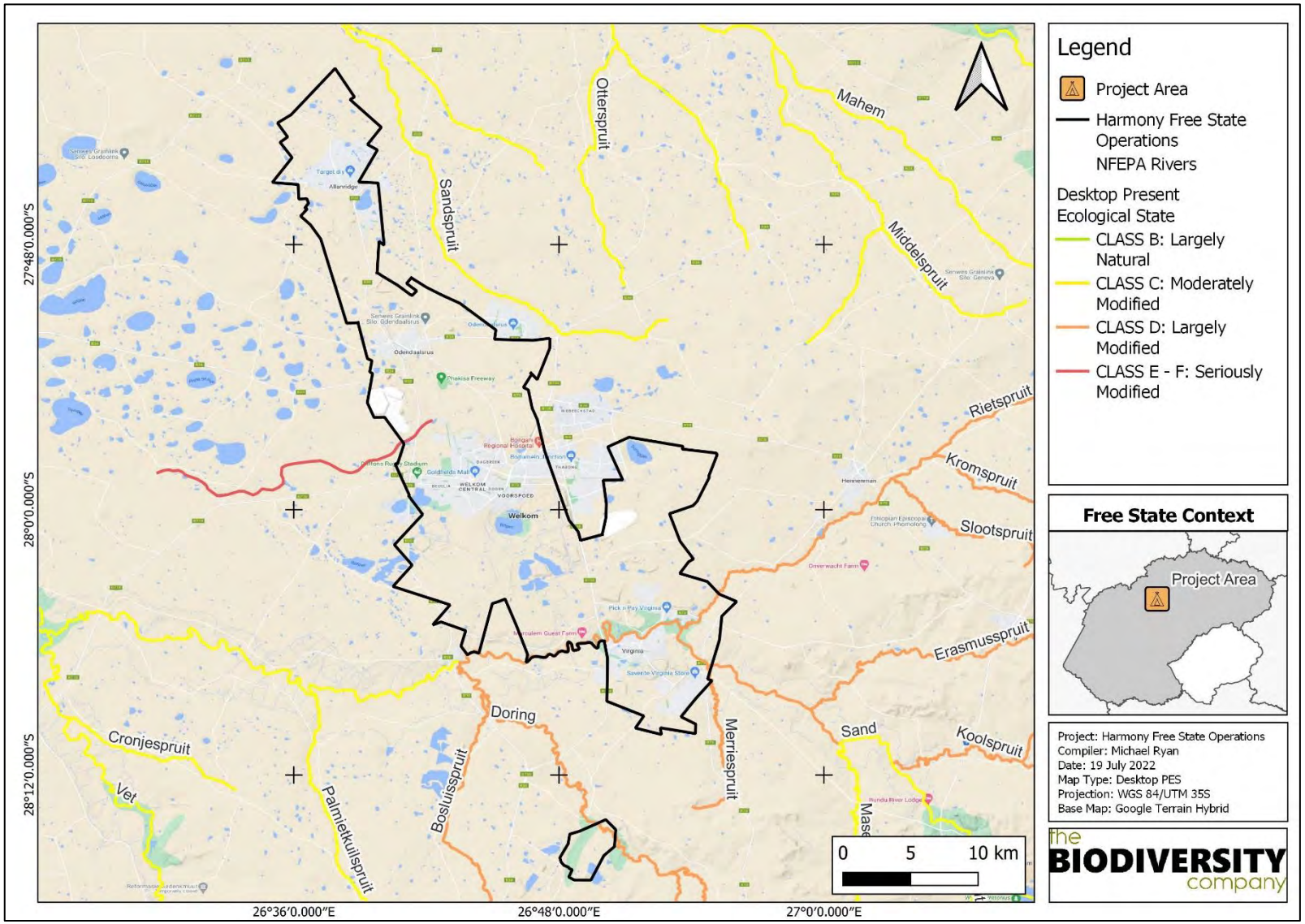


Figure 3-3: Illustration of the Desktop Present Ecological State within the project area

3.3.1 Resource Quality Objectives

The NWA sets out to ensure that water resources are used, managed, and controlled in such a way that they benefit all users. To achieve this, the Act has prescribed a series of measures such as Resource Quality Objectives (RQOs) to ensure comprehensive protection of water resources so that they can be used sustainably (DWA, 2011). Results from the riverine assessment are ideally compared to the RQOs of the Water Management Area (WMA), and at a finer level for specific catchments (where available). RQOs provide numerical and/or descriptive statements about the biological, chemical, and physical attributes that characterise a resource for the level of protection defined by its class. "RQOs might describe, among other things, the quantity, pattern and timing of instream flow; water quality; the character and condition of riparian habitats, as well as the characteristics and condition of the aquatic biota". There are currently nine WMA areas - within the project area of the Vaal WMA - which were formed by joining the old nineteen WMA, with the project area located within the old the Middle Vaal WMA. As a result, the RQOs for the Middle Vaal catchment were considered for this assessment (RSA, 2016). The RQOs for each aspect of the aquatic assessment per river system are presented in Table 3-3. The RQO's for catchment C25F, which drains the Vaal River, were not considered as the river is 62 km downstream of the Harmony Free State Operations and deemed irrelevant.

Table 3-3: Resource Quality Objectives for the relevant catchments

Aspect	RQO	Aspect	RQO
C42H		C25B and C43B	
Merriespruit River		Sandspruit and Mahem River	
Target Ecological Category	C (Moderately Modified)	Target Ecological Category	C (Moderately Modified)
Electrical Conductivity	95th percentile must be less than or equal to 650 µS/cm	Electrical Conductivity	95th percentile must be less than or equal to 700 µS/cm
pH	5th percentile of 6.5; 95th percentile of 8.5 (6.5 – 8.5)	pH	5th percentile of 6.5; 95th percentile of 8.5 (6.5 – 8.5)
SASS5	Maintain the current C category by ensuring the Average Score Per Taxon is >5.0.	SASS5	Maintain the current C category by ensuring the Average Score Per Taxon is >5.0.
Macroinvertebrate Response Assessment Index (MARAI)	≥ C (≥ 62)	Macroinvertebrate Response Assessment Index (MARAI)	≥ C (≥ 62)
Fish Response Assessment Index (FRAI)	≥ C (≥ 62)	Fish Response Assessment Index (FRAI)	≥ C (≥ 62)
Instream Ecostatus category	≥ C (≥ 62)	Instream Ecostatus category	≥ C (≥ 62)
Hydrological category	≥ C (≥ 62)	Hydrological category	≥ C (≥ 62)
Water Quality category	≥ C (≥ 62)	Water Quality category	≥ C (≥ 62)
C42K		C42J	
Doring River		Rietspruit and Sand River	
Target Ecological Category	C/D (Moderately Modified to Largely Modified)	Target Ecological Category	D (Largely Modified)
Electrical Conductivity	95th percentile must be less than or equal to 700 µS/cm	Electrical Conductivity	95th percentile must be less than or equal to 850 µS/cm
pH	5th percentile of 7.5; 95th percentile of 9.2 (7.5 – 9.2)	pH	5th percentile of 6.5; 95th percentile of 9.2 (6.5 – 9.2)
		Fish Response Assessment Index (FRAI)	≥ D (≥ 42)
		Instream Ecostatus category	≥ D (≥ 42)

Aspect	RQO	Aspect	RQO
		Hydrological category	≥ D (≥ 42)
		Water Quality category	≥ D (≥ 42)

3.3.2 Strategic Water Source Areas

Strategic Water Source Areas (SWSAs) are areas that supply a disproportionate amount of mean annual runoff to a geographical region of interest. The areas supplying ≥ 50% of South Africa's water supply (which were represented by areas with a mean annual runoff of ≥ 135 mm/year) represent national SWSAs (SANBI, 2013). According to the SWSAs of South Africa, Lesotho and Swaziland, the project area is not located within the SWSAs as all SWSA are aligned along the coast. The town of Welkom is considered a local steppe climate where summers receive considerably more rain than winters (annual 577 mm), with an average annual temperature in Brits 17.7°C (climate-data.org, 2022).

3.3.3 Freshwater Critical Biodiversity Area

Critical Biodiversity Areas (CBAs) are terrestrial and aquatic areas of the landscape that need to be maintained in a natural or near-natural state to ensure the continued existence and functioning of species, ecosystems, and the delivery of ecosystem services. CBAs are areas of high biodiversity value and need to be kept in a natural state, with no further loss of habitat or species (MTPA, 2014). Thus, if these areas are not maintained in a natural or near natural state then biodiversity targets cannot be met. Maintaining an area in a natural state can include a variety of biodiversity compatible land and resource uses (SANBI, 2017).

According to the Terrestrial Critical Biodiversity Areas for the Free State layer, which covers the entirety of the province, the status of all freshwater biodiversity systems can be assessed as they flow through the delineated habitat. This indicates that the extensive footprint of the Harmony Free State Operations traverses through a multitude of different habitat types with different sensitivities (Figure 3-4). The project area is comprised of Critical Biodiversity Area Two (0.24 %), Ecological Support Area One (5.54 %), Other Natural Areas (6.26 %), Critical Biodiversity Area One (11.02 %), Ecological Support Area Two (31.72 %) and Degraded Areas (45.22 %). This indicates that the majority of the habitat within the Harmony Free State Operations is degraded. None of the watercourses within the project area coincide with the degraded areas however and cut through habitats considered as either Ecological Support Area One or Ecological Support Area Two with small sections considered Critical Biodiversity Area One or Other Natural Areas.

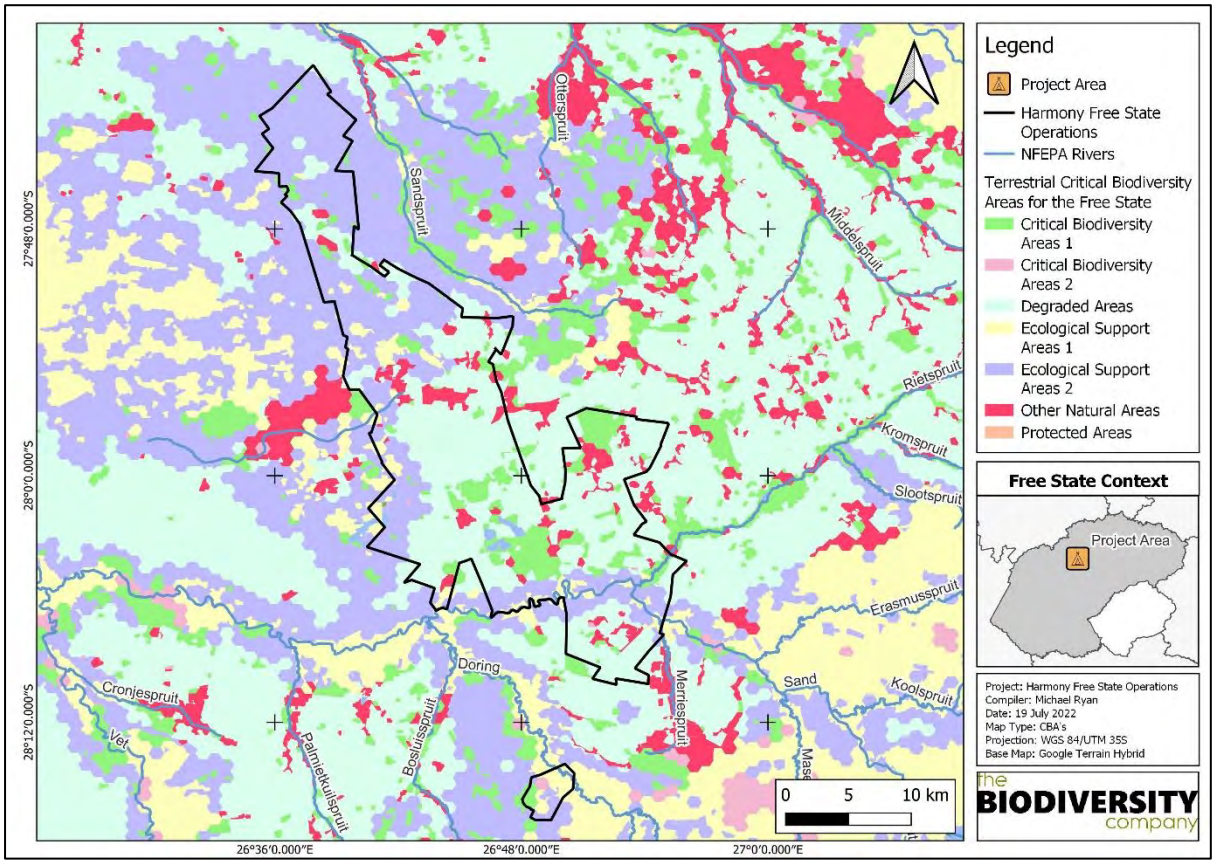


Figure 3-4: Illustration of the Freshwater Critical Biodiversity Areas within the project area (SANBI, 2008)

3.3.4 Ecosystem Threat Status

Ecosystem threat status outlines the degree to which ecosystems are still intact or, alternatively, losing vital aspects of their structure, function, and composition on which their ability to provide ecosystem services ultimately depends (Skowno *et al*., 2019).

Ecosystem types are categorised as Critically Endangered (CR), Endangered (EN), Vulnerable (VU) or Least Threatened (LT) based on the proportion of each ecosystem type that remains in good ecological condition (Skowno *et al*., 2019). The Ecosystem Threat Status (ETS) of each river assessed was based on the extent to which the system had been modified from its natural condition (SANBI, 2018). According to the South African Inventory of Inland Aquatic Ecosystems (SAIIAE) released with the National Biodiversity Assessment (NBA) of rivers, the rivers which were superimposed on the aquatic ecosystem threat status indicate that all the SQRs within the project area are considered to be *Critically Endangered* ecosystems (Figure 3-5).

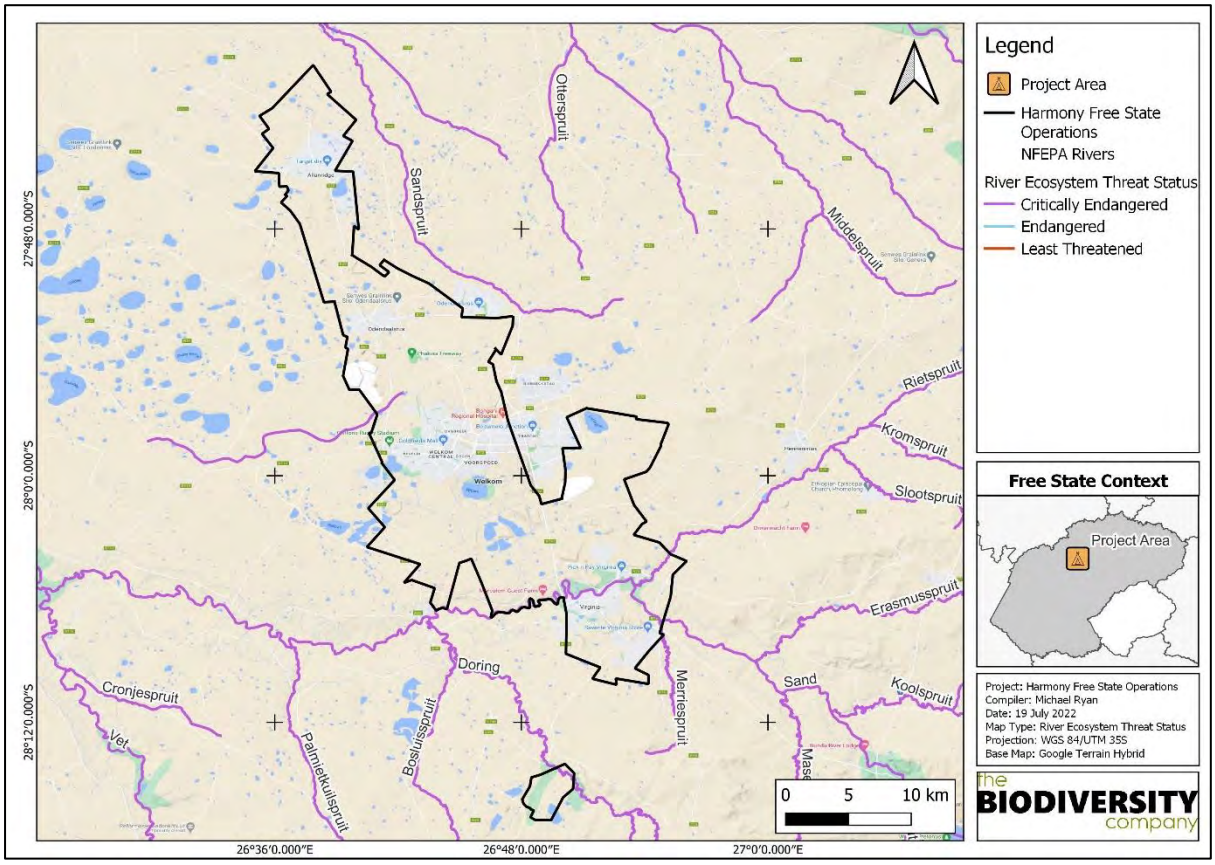


Figure 3-5: Illustration of the Ecosystem Threat Status of the project area (SANBI, 2018)

3.3.5 Ecosystem Protection Level

The Ecosystem Protection Level (EPL) indicates whether ecosystems are adequately protected or under-protected. Ecosystem types are categorised as not protected, poorly protected, moderately protected or well protected, based on the proportion of each ecosystem type that occurs within a protected area recognised in the Protected Areas Act (Skowno *et al*., 2019). The EPL of each river assessed was based on the extent (expressed as a percentage) to which the system has their biodiversity target located within protected areas and are in a natural or near-natural ecological condition. Rivers in protected areas need to be in a good condition (A or B ecological category) to be considered as protected. Well protected rivers are 100% located within protected areas; while moderately protected and poorly protected river ecosystem types have at least 50% and 5% of their biodiversity target in protected areas, respectively. Not protected rivers form less than 5% (SANBI, 2018).

The project area was superimposed on the ecosystem protection level map to assess the protection status of aquatic ecosystems associated with the development (Figure 3-6). This indicates that the SQRs of the project area are considered to be *poorly protected,* with the upper reaches of select SQRs considered *not protected.*

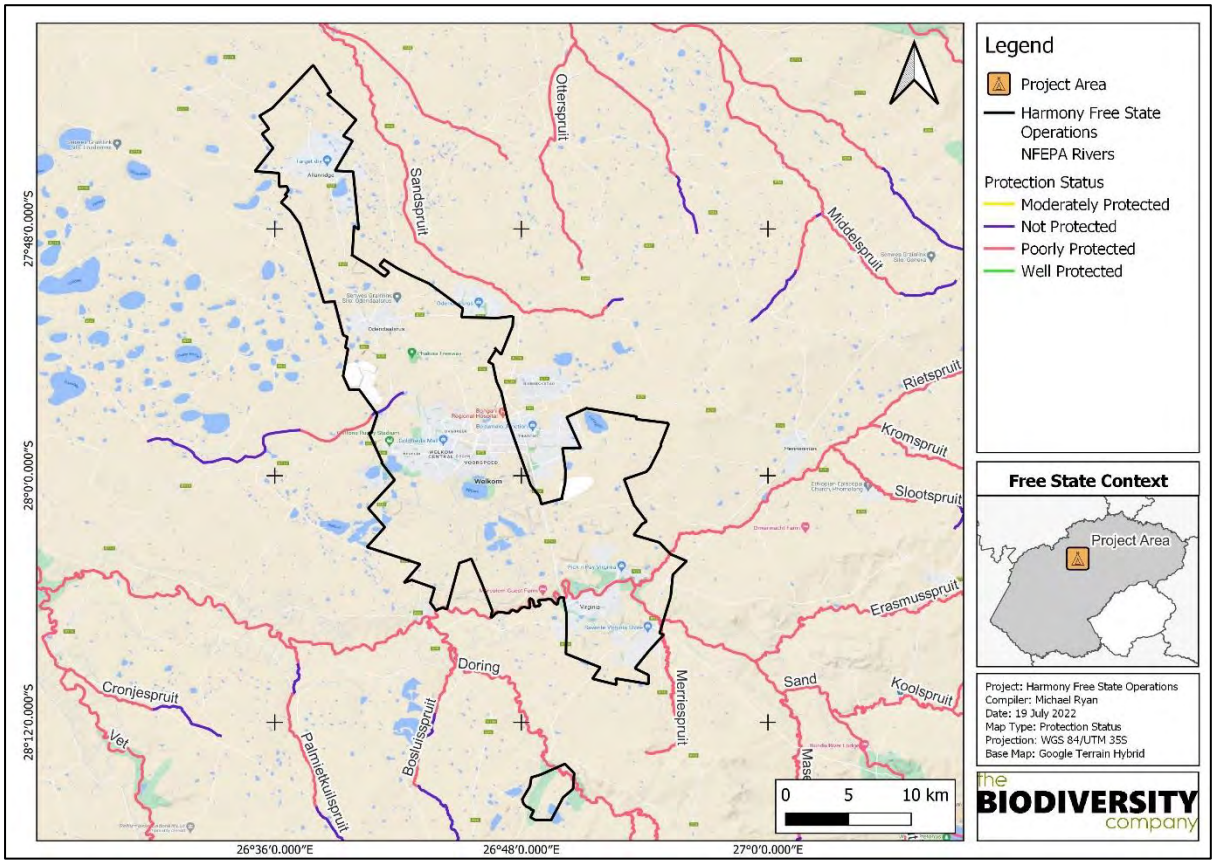


Figure 3-6: Illustration of the Ecosystem Protection Level of the project area (NBA, 2018)

3.4 Expected Fish Species

An expected species list was generated from DWS (2014) and Skelton (2011) for the nine SQRs within the project area. A total of ten fish species are expected to occur in the greater project area with varying species expected in the different reaches as presented in Table 3-4. The conservational status of fish species was assessed against the International Union for Conservation of Nature (IUCN) database (IUCN, 2022).

The expected species are generated on a reach basis, and the occurrence of all species in the system is unlikely as different species are specialists of different habitats which are present along a reach. This was observed as the species list for the project was relatively uniform. However, some species were not found within specific reaches but are expected within the majority of the systems. Fish species are also sensitive to water quality with sensitive species not expected in degraded systems. The expected species per reach therefore varies according to habitat and physico-chemical properties of a system. As a result, the frequency of occurrence of these species was included into the Table 3-4 where 0 indicates not expected, 1 indicates seldom expected, 3 indicates sometimes expected and 5 indicates always expected. All expected species are of Least Concern (LC).

Table 3-4: Expected fish species

Species	Common Name	IUCN Status (2022)	Sandspruit River	Sandspruit River	Mahem River	Rietspruit River	Sand River	Merriespruit River	Sand River	Doring River
			C25B – 02400	C25B – 02423	C43B - 02577	C42J - 02590	C42J - 02716	C42H - 02745	C42J – 02578	C42K - 02754
Austroglanis sclateri	Rock-catfish	LC	0	0	0	1	1	0	1	1
Clarias gariepinus	Sharptooth Catfish / Barbel	LC	5	5	3	5	5	5	5	3
Enteromius anoplus	Cubbyhead Barb	LC	3	3	3	3	3	3	3	3
Enteromius paludinosus	Straightfin Barb	LC	5	3	3	3	1	0	1	3
Labeo cylindricus	African Carp	LC	3	0	0	3	3	3	3	3
Labeo umbratus	Moggel	LC	3	5	0	3	5	0	5	3
Labeobarbus aeneus	Smallmouth Yellowfish	LC	3	3	0	3	5	3	5	3
Labeobarbus kimberleyensis	Largemouth yellowfish	NT	0	0	0	0	1	0	1	1
Pseudocrenilabrus philander	Southern Mouth-Brooder	LC	5	5	5	3	5	5	5	4
Tilapia sparrmanii	Banded Tilapia	LC	5	5	5	3	5	5	5	4
Total Species			8	7	5	9	10	6	10	10

LC - Least Concern, NT – Near Threatened, VU – Vulnerable

4 Limitations and Assumptions

The following aspects were considered as limitations of the assessment:

- All information received from the client is relevant and accurate;
- A single season aquatic ecology survey was completed for this assessment. Thus, temporal trends were not investigated;
- Due to the amount of sampling sites selected, the survey required 2 separate weeks of sampling which were separated by a week due to logistical issues;
- No baseline biomonitoring data/report(s) are available for the project area. Therefore, information presents the findings of the single aquatic survey;
- No distinction between natural and artificial wetland systems were made as this falls outside of the scope of work;
- Locating all sources of modifications unrelated to mining activity under the Harmony Free State Operations to watercourses assessed falls outside of the scope of work of this report;
- Understanding exchanges and relationships of dissolved solids under a salt balance falls outside the scope of work of this report;
- Due to the rapid nature of the assessment and the survey methods applied, fish diversity and abundance was likely to be underestimated; and
- Due to the size of the proposed area only the key areas where infrastructure is located were focused on, the remaining areas were predominantly delineated through means of desktop.

Despite the listed limitations for this assessment, it is the specialist opinion that the content within the report is considered adequate to meet the scope of work provided. Its outcomes should just be interpreted with the limitations in mind.

5 Methodology

The following study approach (or method) was implemented for the baseline assessment phase of the project, following, and/or including the field survey conducted from the 3rd to the 6th of May 2022. With a follow up survey conducted on the 12th and 13th of May 2022 to complete the required fieldwork. This constitutes a low flow survey. There is however no limitation with regard to the timing of the survey. The selected methodology was applied due to the identified sensitivity of the watercourses by desktop data, with the exact methodology applied based on the scope of work which defined the considered aspects of the project to consider.

5.1 Wetlands Assessment

5.1.1 Identification and Mapping

The wetland areas are delineated in accordance with the DWAF (2005) guidelines, a cross section is presented in Figure 5-1. The outer edges of the wetland areas were identified by considering the following four specific indicators:

- The Terrain Unit Indicator helps to identify those parts of the landscape where wetlands are more likely to occur;
- The Soil Form Indicator identifies the soil forms, as defined by the Soil Classification Working Group (1991), which are associated with prolonged and frequent saturation;

- The soil forms (types of soil) found in the landscape were identified using the South African soil classification system namely, Soil Classification: A Taxonomic System for South Africa;

- The Soil Wetness Indicator identifies the morphological "signatures" developed in the soil profile as a result of prolonged and frequent saturation; and

- The Vegetation Indicator identifies hydrophilic vegetation associated with frequently saturated soils.

Vegetation is used as the primary wetland indicator. However, in practise the soil wetness indicator tends to be the most important, and the other three indicators are used in a confirmatory role.

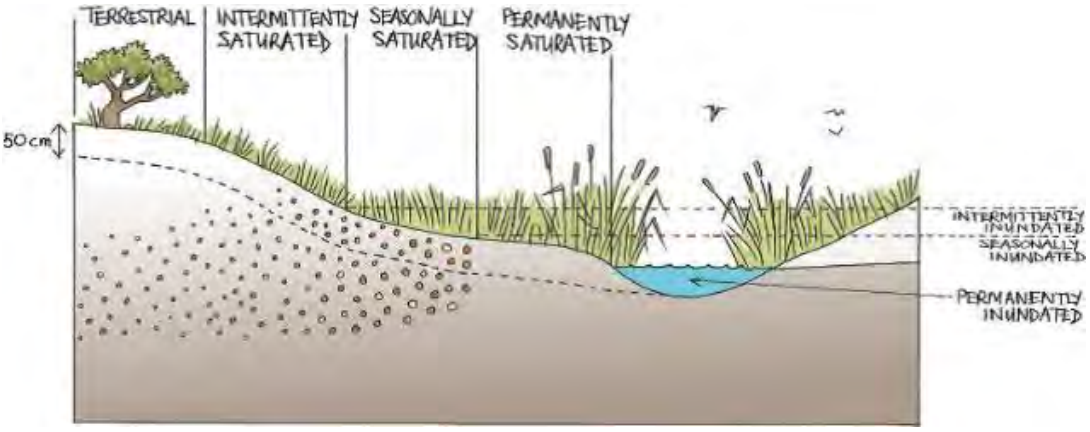


Figure 5-1: Cross section through a wetland, indicating how the soil wetness and vegetation indicators change (Ollis et al. 2013)

5.1.2 Ecological Classification and Description

The National Wetland Classification Systems (NWCS) developed by the South African National Biodiversity Institute (SANBI) was considered for this study. This system comprises a hierarchical classification process of defining a wetland based on the principles of the hydrogeomorphic (HGM) approach at higher levels, and then also includes structural features at the lower levels of classification (Ollis et al. 2013).

5.1.3 Determining Buffer Requirements

The “Preliminary Guideline for the Determination of Buffer Zones for Rivers, Wetlands and Estuaries” (Macfarlane et al. 2014) was used to determine the appropriate buffer zone for the proposed activity.

5.2 Aquatics Assessment

5.2.1 Water Quality

Water quality was measured *in situ* using a handheld calibrated Ex Tech meter. The constituents considered that were measured included: pH, electrical conductivity (EC) (µS/cm) and water temperature (°C).

5.2.2 Habitat Assessments

Habitat availability and diversity are major attributes for the biota found in a specific ecosystem, and thus knowledge of the quality of habitats is important in an overall assessment of ecosystem health. Habitat assessment can be defined as the evaluation of the structure of the surrounding physical habitat that influences the quality of the water resource and the condition of the resident aquatic community

(Barbour *et al*. 1996). Both the quality and quantity of available habitat affect the structure and composition of resident biological communities (USEPA, 1998). Habitat quality and availability plays a critical role in the occurrence of aquatic biota. For this reason, habitat evaluation is conducted simultaneously with biological evaluations to facilitate the interpretation of results.

5.2.3 Intermediate Habitat Integrity Assessment

The Intermediate Habitat Integrity Assessment (IHIA) model was used to assess the integrity of the habitats from a riparian and instream perspective as described in Kleynhans (1996). The habitat integrity of a river refers to the maintenance of a balanced composition of physico-chemical and habitat characteristics on a temporal and spatial scale which are comparable to the characteristics of natural habitats of the region (Kleynhans, 1996). The project area includes six NFEPA rivers namely the Sandspruit River, Mahem River, Rietspruit River, Sand River, Merriespruit River and Doring River, which are the focus of the assessment. The eight SQR's were considered with some joined which formed part of the same river. The reaches which pertain to the Harmony Free State Operations were assessed and were considered when completing the IHIA.

This model compares current conditions with reference conditions that are expected to have been present. Specification of the reference condition follows an impact-based approach where the intensity and extent of anthropogenic changes are used to interpret the impact on the habitat integrity of the system. To accomplish this, information on abiotic changes that can potentially influence river habitat integrity are obtained from surveys or available data sources. These changes are all related and interpreted in terms of modification of the drivers of the system, namely hydrology, geomorphology, and physico-chemical conditions and how these changes would impact on the natural riverine habitats. The criteria and ratings utilised in the assessment of habitat integrity in the current study are presented in Table 5-1 and Table 5-2 respectively. The spatial framework for each IHIA was 5 km upstream and downstream of the respective sampling points within the watercourse. This was extended for select systems which flow through the Harmony Free State Operations to assess the entire section.

Table 5-1: Criteria used in the assessment of habitat integrity (Kleynhans, 1996)

Criterion	Relevance
Water abstraction	Direct impact on habitat type, abundance, and size. Also implicated in flow, bed, channel, and water quality characteristics. Riparian vegetation may be influenced by a decrease in the supply of water.
Flow modification	Consequence of abstraction or regulation by impoundments. Changes in temporal and spatial characteristics of flow can have an impact on habitat attributes such as an increase in duration of low flow season, resulting in low availability of certain habitat types or water at the start of the breeding, flowering, or growing season.
Bed modification	Regarded as the result of increased input of sediment from the catchment or a decrease in the ability of the river to transport sediment (Gordon *et al*., 1993). Indirect indications of sedimentation are stream bank and catchment erosion. Purposeful alteration of the stream bed, e.g., the removal of rapids for navigation (Hilden & Rapport, 1993) is also included.
Channel modification	May be the result of a change in flow, which may alter channel characteristics causing a change in marginal instream and riparian habitat. Purposeful channel modification to improve drainage is also included.
Water quality modification	Originates from point and diffuse point sources. Measured directly or alternatively agricultural activities, human settlements and industrial activities may indicate the likelihood of modification. Aggravated by a decrease in the volume of water during low or no flow conditions.
Inundation	Destruction of riffle, rapid and riparian zone habitat. Obstruction to the movement of aquatic fauna and influences water quality and the movement of sediments (Gordon *et al*., 1992).
Exotic macrophytes	Alteration of habitat by obstruction of flow and may influence water quality. Dependent upon the species involved and scale of infestation.
Exotic aquatic fauna	The disturbance of the stream bottom during feeding may influence the water quality and increase turbidity. Dependent upon the species involved and their abundance.

Criterion	Relevance
Solid waste disposal	A direct anthropogenic impact which may alter habitat structurally. Also, a general indication of the misuse and mismanagement of the river.
Indigenous vegetation removal	Impairment of the buffer the vegetation forms to the movement of sediment and other catchment runoff products into the river (Gordon *et al*., 1992). Refers to physical removal for farming, firewood, and overgrazing.
Exotic vegetation encroachment	Excludes natural vegetation due to vigorous growth, causing bank instability and decreasing the buffering function of the riparian zone. Allochtonous organic matter input will also be changed. Riparian zone habitat diversity is also reduced.
Bank erosion	Decrease in bank stability will cause sedimentation and possible collapse of the riverbank resulting in a loss or modification of both instream and riparian habitats. Increased erosion can be the result of natural vegetation removal, overgrazing or exotic vegetation encroachment.

Table 5-2: Descriptions used for the Ratings of the Various Habitat Criteria

Impact Category	Description	Impact Score
None	No discernible impact or the modification is located in such a way that it has no impact on habitat quality, diversity, size and variability.	0
Small	The modification is limited to very few localities and the impact on habitat quality, diversity, size and variability are also very small.	1-5
Moderate	The modifications are present at a small number of localities and the impact on habitat quality, diversity, size and variability are also limited.	6-10
Large	The modification is generally present with a clearly detrimental impact on habitat quality, diversity, size and variability. Large areas are, however, not influenced.	11-15
Serious	The modification is frequently present and the habitat quality, diversity, size and variability in almost the whole of the defined area are affected. Only small areas are not influenced.	16-20
Critical	The modification is present overall with a high intensity. The habitat quality, diversity, size and variability in almost the whole of the defined section are influenced detrimentally.	21-25

5.2.4 Aquatic Macroinvertebrate Assessment

Macroinvertebrate assemblages are good indicators of localised conditions because many benthic macroinvertebrates have limited migration patterns or a sessile mode of life. They are particularly well-suited for assessing site-specific impacts (upstream and downstream studies) (Barbour *et al.* 1999). Benthic macroinvertebrate assemblages are made up of species that constitute a broad range of trophic levels and pollution tolerances, thus providing strong information for interpreting cumulative effects (Barbour *et al.* 1999). The assessment and monitoring of benthic macroinvertebrate communities forms an integral part of the monitoring of the health of an aquatic ecosystem.

5.2.4.1 South African Scoring System

The South African Scoring System version 5 (SASS5) is the current index being used to assess the status of riverine macroinvertebrates in South Africa. According to Dickens and Graham (2002), the index is based on the presence of aquatic invertebrate families and the perceived sensitivity to water quality changes of these families. Different families exhibit different sensitivities to pollution, these sensitivities range from highly tolerant families (e.g., *Chironomidae*) to highly sensitive families (e.g., *Perlidae*). SASS results are expressed both as an index score (SASS score) and the Average Score Per recorded Taxon (ASPT value).

Sampling of aquatic invertebrate families was conducted according to the SASS5 methodology outlined by Dickens and Graham (2002) where a specialist assesses a variety of biotopes which include Stones (S), Vegetation (Veg) Gravel, sand and mud (GSM) which are all sampled by making use of a net (1 mm mesh net on a 30 cm square frame) according to the prescribed timeframes or areas which need to be sampled for a representative sample. This is supplemented by hand-picking and visual

observation per the described SASS5 methodology. All three samples are collected separately according to the separate biotopes and then placed in a white or cream flat-bottomed tray/s (approximately 'A3' or 30 x 45cm size and 10 cm deep) in which all sampled invertebrates are identified.

Sampled invertebrates were identified using the "Aquatic Invertebrates of South African Rivers" Illustrations book, by Gerber and Gabriel (2002). Identification of organisms was made to family level (Thirion *et al.* 1995; Dickens and Graham, 2002; Gerber and Gabriel, 2002; Fry, 2022).

All SASS5 and ASPT scores are compared with the SASS5 Data Interpretation Guidelines (Dallas, 2007) for the Highveld – Lower ecoregion (Figure 5-2). This method seeks to develop biological bands depicting the various ecological states and is derived from data contained within the Rivers Database and supplemented with other data not yet in the database. The interpretation/description of the state of a system according to its calculated class based on the biological bands is presented inTable 5-3.

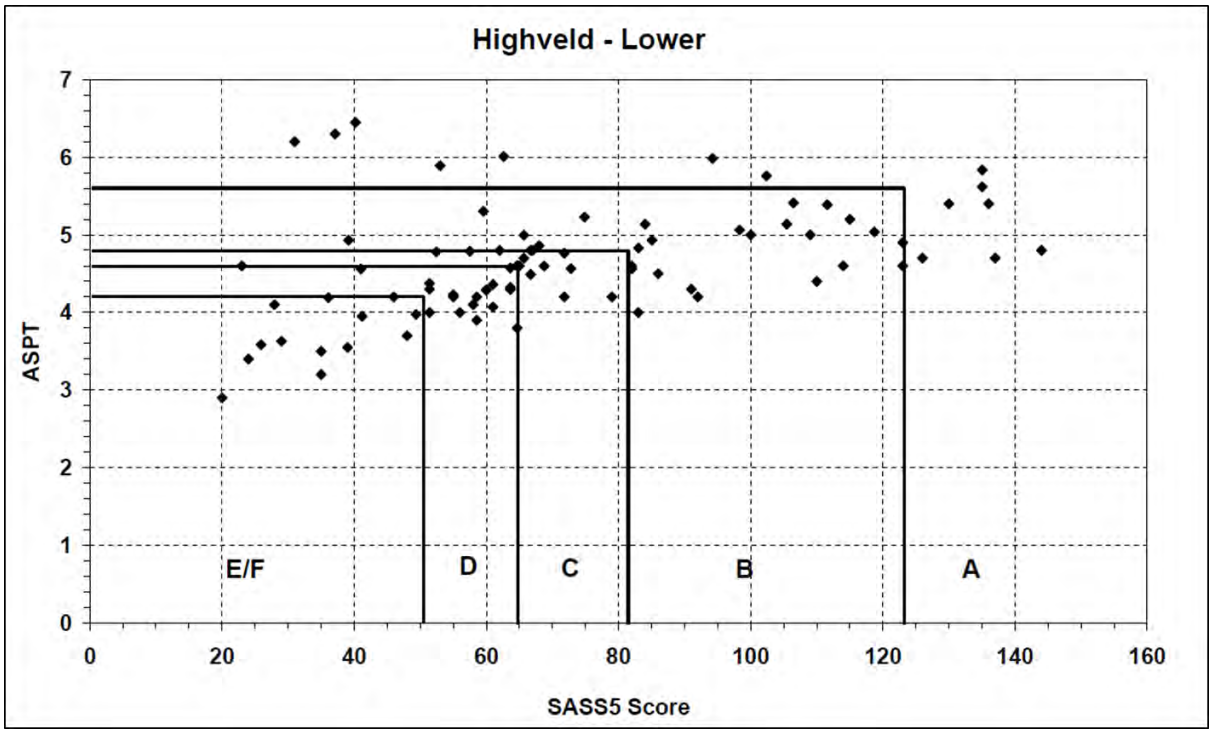


Figure 5-2: Guidelines used for the Interpretation and Classification of the SASS5 Scores (Dallas, 2007)

Table 5-3: Biological Bands / Ecological categories for interpreting SASS5 data (adapted from Dallas, 2007)

Class	Ecological Category	Description
A	Natural	Unimpaired. High diversity of taxa with numerous sensitive taxa.
B	Largely natural	Slightly impaired. High diversity of taxa, but with fewer sensitive taxa.
C	Moderately modified	Moderately impaired. Moderate diversity of taxa.
D	Largely modified	Considerably impaired. Mostly tolerant taxa present.
E/F	Seriously Modified	Severely impaired. Only tolerant taxa present.

5.2.4.2 Macroinvertebrate Response Assessment Index

Aquatic macroinvertebrate assemblages and communities offer a good understanding of the flow regime and water quality in a river. In addition, they form an essential component of the riverine ecosystem. Macroinvertebrates are important processors of transported organic matter in aquatic systems, perform vital functions in purifying the water and furthermore provide a food source for aquatic

and terrestrial biota. Aquatic macroinvertebrate assemblages are guided by the physical-chemical tolerance of the individuals in the population to an array of environmental influences. The distribution pattern resulting from habitat selection by a given aquatic macroinvertebrate species reflects the optimal overlap between habit (mode of existence) and physical environmental conditions such as habitat and flows. Therefore, the often-discontiguous distribution of aquatic macroinvertebrate populations is a result of interplay between habitat, habit and the availability of food resources.

The Macroinvertebrate Response Assessment Index (MIRAI) was used to provide a habitat-based cause-and-effect foundation to interpret the deviation of the aquatic invertebrate community from the calculated reference conditions for the SQR. This does not preclude the calculation of SASS5 scores if required (Thirion, 2007). The four major components of a stream system that determine productivity for aquatic macroinvertebrates are as follows:

- Flow regime;
- Physical habitat structure;
- Water quality; and
- Energy inputs from the watershed.

According to Thirion (2007), the determination of aquatic invertebrate EC is done by integrating the ecological requirements of the invertebrate taxa in a community or assemblage and their response to modified habitat conditions. These are based on an interpretation of the environmental requirements, preferences an intolerance of Invertebrate taxa constituting the natural assemblage in a particular river delineation, and their responses to changes in habitat conditions as brought about by changes in driver components. The results of the MIRAI will provide an indication of the current ecological category and therefore assist in the determination of the Present Ecological Status (PES).

5.2.5 Fish Community Assessment

A standard qualitative fish assessment was completed for this study making use of rapid electrofishing techniques to determine the reach-based fish community during the survey for comparative purposes and interpretation. All fish were identified in the field and released at the point of capture, so as not to cross fish populations. Fish species were identified using the guide Freshwater Fishes of Southern Africa (Skelton, 2001). The identified fish species were compared to those expected to be present for the quaternary catchment. The expected fish species list for the reach was developed from a literature survey to compare to the sampled species at site. Different fish species represent different sensitivities to water chemistry, habitat and flow which are considered

5.2.5.1 Fish Response Assessment Index

Fish have different sensitivities or levels of tolerance to various aspects that they are subjected to within the aquatic environment. These tolerance levels are rated with a sensitivity score as presented in Table 5-4. These tolerance levels are scored to show each fish species' sensitivity to flow and physico-chemical modifications. This applies as an average of the whole class and not each individual species.

Table 5-4: Intolerance rating and sensitivity of fish species

Sensitivity Score	Tolerance/Sensitivity Level
0-1	Highly tolerant = Very low sensitivity
1-2	Tolerant = Low sensitivity
2-3	Moderately tolerant = Moderate sensitivity
3-4	Moderately intolerant = High sensitivity
4-5	Intolerant = Very high sensitivity

Biological responses are important to consider and therefore the qualitative data obtained from the surveys was utilized in the Fish Response Assessment Index (FRAI) (Kleynhans, 2007) and with the results presented below (Table 5-4). The Frequency of Occurrence (FROC) of the sampled fish community is calculated as follows: 0 = Absent; 1 = Present at very few sites (<10%); 2 = Present at few sites (>10-25%); 3 = Present at about >25-50% of sites; 4 = Present at most sites (>50- 75%); 5 = Present at almost all sites (>75%).

The results of the FRAI will provide an indication of the current ecological category and therefore assist in the determination of the PES.

5.2.6 Present Ecological Status

Ecological classification refers to the determination and categorisation of the integrity of the various selected biophysical attributes of ecosystems compared to the natural or close to natural reference conditions (Kleynhans and Louw, 2007). For the purpose of this study ecological classifications have been determined for biophysical attributes for the associated water course. This was completed using the river ecoclassification manual by Kleynhans and Louw (2007).

5.3 Risk Assessment

The risk assessment was completed in accordance with the requirements of the DWS' General Authorisation (GA) in terms of Section 39 of the NWA for water uses as defined in Section 21(c) or Section 21(i) (GN 509 of 2016). The significance of the impact is calculated according to Table 5-5.

Table 5-5: Significance ratings matrix

Rating	Class	Management Description
1 – 55	(L) Low Risk	Acceptable as is or consider requirement for mitigation. Impact to watercourses and resource quality small and easily mitigated. Wetlands may be excluded.
56 – 169	M) Moderate Risk	Risk and impact on watercourses are notably and require mitigation measures on a higher level, which costs more and require specialist input. Wetlands are excluded.
170 – 300	(H) High Risk	Always involves wetlands. Watercourse(s)impacts by the activity are such that they impose a long-term threat on a large scale and lowering of the Reserve.

6 Results and Discussions

6.1 Wetland Assessment

6.1.1 Delineation and Description

Four (4) different wetland types, comprising numerous individual HGM units were delineated in accordance with the DWAF (2005) guidelines. The four different types were classified as being channelled valley bottoms, unchannelled valley bottoms, hillslope seeps and depression wetlands.

6.1.2 Unit Setting

The channelled valley bottom wetland is located on the "valley floor" landscape unit. Channelled valley bottom wetlands are typically found on valley-floors with a clearly defined, finite stream channel and lacks floodplain features, referring specifically to meanders. Channelled valley bottom wetlands are known to undergo loss of sediment in cases where the wetlands' slope is high and the deposition thereof in cases of low relief. Figure 6-1 illustrates a diagram of the channelled valley bottom wetland, showing the dominant movement of water into, through and out of the system.

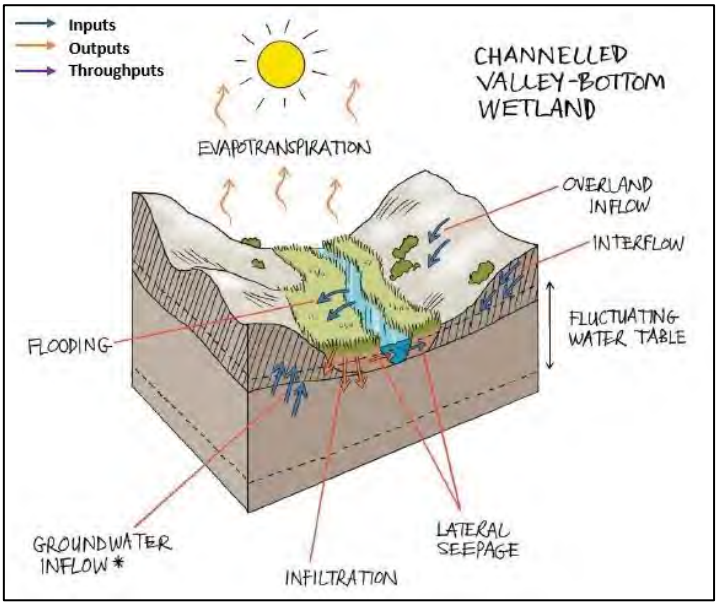


Figure 6-1: Amalgamated diagram of a typical channelled valley bottom wetland, highlighting the dominant water inputs, throughputs and outputs, SANBI guidelines (Ollis et al. 2013)

Depression wetlands are typically located on the “valley-floor” landscape unit. Depressions are inward draining basins with an enclosing topography which allows for water to accumulate within the system. Depressions, in some cases, are also fed by lateral sub-surface flows in cases where the dominant geology allows for these types of flows. Figure 6-2 illustrates a diagram of a depression, showing the dominant movement of water into, through and out of the system.

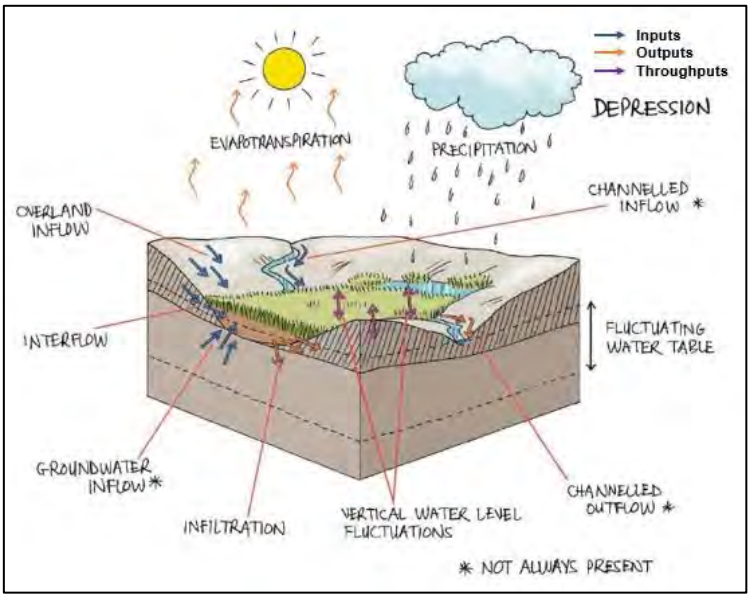


Figure 6-2: Amalgamated diagram of a typical depression wetland, highlighting the dominant water inputs, throughputs and outputs, SANBI guidelines (Ollis et al. 2013)

Hillslope seeps are located within slopes, as mentioned in Figure 6-3. Isolated hillslope seeps are characterised by colluvial movement of material. These systems are fed by very diffuse sub-surface flows which seeps out at very slow rates, ultimately ensuring that no direct surface water connects this wetland with other water courses within the valleys. Figure 6-3 illustrates a diagram of the hillslope seeps, showing the dominant movement of water into, through and out of the system.

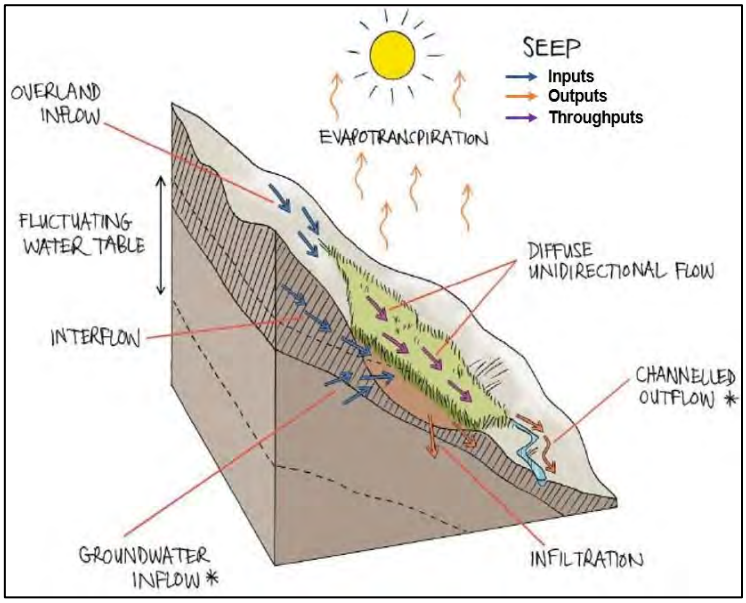


Figure 6-3: Amalgamated diagram of a typical hillslope seep wetland, highlighting the dominant water inputs, throughputs and outputs, SANBI guidelines (Ollis et al. 2013)

The unchannelled valley bottom is located on the "valley floor" landscape unit. Unchannelled valley bottom wetlands are typically found on valley-floors where the landscape does not allow high energy flows. Figure 6-4 illustrates a diagram of a typical unchannelled valley bottom, showing the dominant movement of water into, through and out of the system.

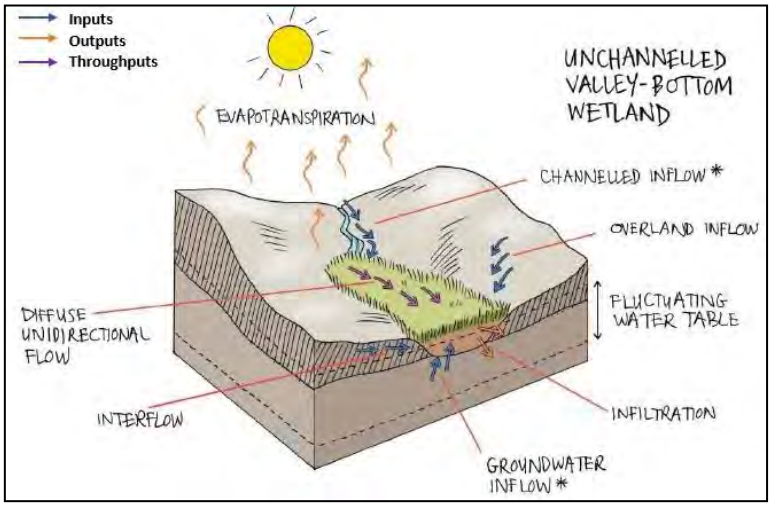


Figure 6-4: Amalgamated diagram of a typical unchannelled valley bottom wetland, highlighting the dominant water inputs, throughputs, and outputs, SANBI guidelines (Ollis et al. 2013)

6.1.3 Wetland Indicators

According to (DWAF, 2005), a combination of hydromorphic soils and hydrophytic plants must be used to identify and accurately delineate wetland areas.

6.1.3.1 Hydromorphic Soils

According to (DWAF, 2005), soils are the most important characteristic of wetlands to accurately identify and delineate wetland areas. Five dominant soil forms were identified within the identified wetland, namely the Katspruit, Kroonstad, Longlands, Westleigh and Mispah soil forms (Soil Classification Working Group, 2018).

The Katspruit soil form consists of an orthic topsoil on top of a gleyic horizon. The “2210” family group is applicable to this soil form given the grey colours, the firm texture and structure of the soil form and the absence of lime.

The Kroonstad soil form consists of an Orthic topsoil on top of an Albic horizon, which in turn is underlain by a Gleyic horizon. The soil family group identified for the Kroonstad soil form is “1110” due to the gleyed colour of the topsoil, the Albic horizon’s grey colours when in a wet condition as well as the non-calcareous nature of the soil.

The Longlands soil form consists of an orthic topsoil on top of an albic horizon. The soil family group identified for the Longlands soil form on-site has been classified as the “1000” soil family due to the grey colour of the soil in wet conditions.

The Westleigh soil form consists of an Orthic A-horizon on top of a Soft Plinthic B-horizon. The soil family group identified for the Westleigh soil form on-site has been classified as the Helena (1000) soil family given the lack of evidence pertaining to luvic processes.

The Mispah soil form consists of an orthic topsoil on top of a hard rock layer. The soil family group identified for the Mispah soil form on-site is that of *2120* due to the chromic properties of the topsoil, the absence of lime as well as the solid structure of the bedrock.

Orthic topsoils are mineral horizons that have been exposed to biological activities and varying intensities of mineral weathering. The climatic conditions and parent material ensure a wide range of properties differing from one orthic topsoil to another (i.e., colouration, structure etc.) (Soil Classification Working Group, 2018).

Albic horizons are often characterised by uniform white-greyish colours from the residual clay and quartz particles making up the matrix of the horizon. The main characteristic of this diagnostic horizon is a bleached colouration, which is a resultant product of distinct redox and ferrolysis pedological processes combined with eluvial processes. According to the Soil Classification Working Group (2018), albic horizons often receive lateral sub-surface flows from hillslope processes.

Gley horizons that are well developed and have homogenous dark to light grey colours with smooth transitions. Stagnant and reduced water over long periods is the main factor responsible for the formation of a gley horizon and could be characterised by green or blue tinges due to the presence of a mineral called Fougerite which includes sulphate and carbonate complexes. Even though grey colours are dominant, yellow and/or red striations can be noticed throughout a gley horizon. The structure of a gley horizon mostly is characterised as strong pedal, with low hydraulic conductivities and a clay texture, although sandy gley horizons are known to occur. The gley soil form commonly occurs at the toe of hillslopes (or benches) where lateral water inputs (sub-surface) are dominant, and the underlying geology is characterised by a low hydraulic conductivity. The gley horizon usually is second in diagnostic sequence in shallow profiles yet is known to be lower down in sequence and at greater depths (Soil Classification Working Group, 2018).

The accumulations of iron (and in some cases manganese) as hydroxides and oxides with the presence of high chroma striations and concretions with black matrixes are associated with the Soft Plinthic horizon. This diagnostic horizon forms due to fluctuating levels of saturation. The iron and manganese concentration result in soft marks within the soil matrix which transform in concretions with high consistencies (Soil Classification Working Group, 1991).

If this process continues for long enough periods, a massive continues impermeable layer of hard plinthite forms. A Soft Plinthic horizon and a Hard Plinthic horizon can be distinguished from one another by means of a simple spade test. A Soft Plinthic horizon can be penetrated by means of a spade in wet conditions whereas a Hard Plinthic horizon cannot (Soil Classification Working Group, 1991).

According to Soil Classification Working Group (2018), this horizon commonly occurs as a result of hillslope hydrology in flat, sandy landscapes. This horizon is known to have an apedal structure together with the presence of concretions.

The hard rock layer disallows infiltration of water or root systems and occur in shallow profiles. Horizontally layered, hard sediments without evidence of vertical seems fall under this category.

6.1.3.2 Hydrophytes

Vegetation plays a considerable role in identifying, classifying and accurately delineating wetlands (DWAF, 2005). During the site visit, various hydrophytic species were identified (including facultative species). Examples include *Cyperus spp,. Persicaria* spp., *Typha Capensis* (See Figure 6-5).

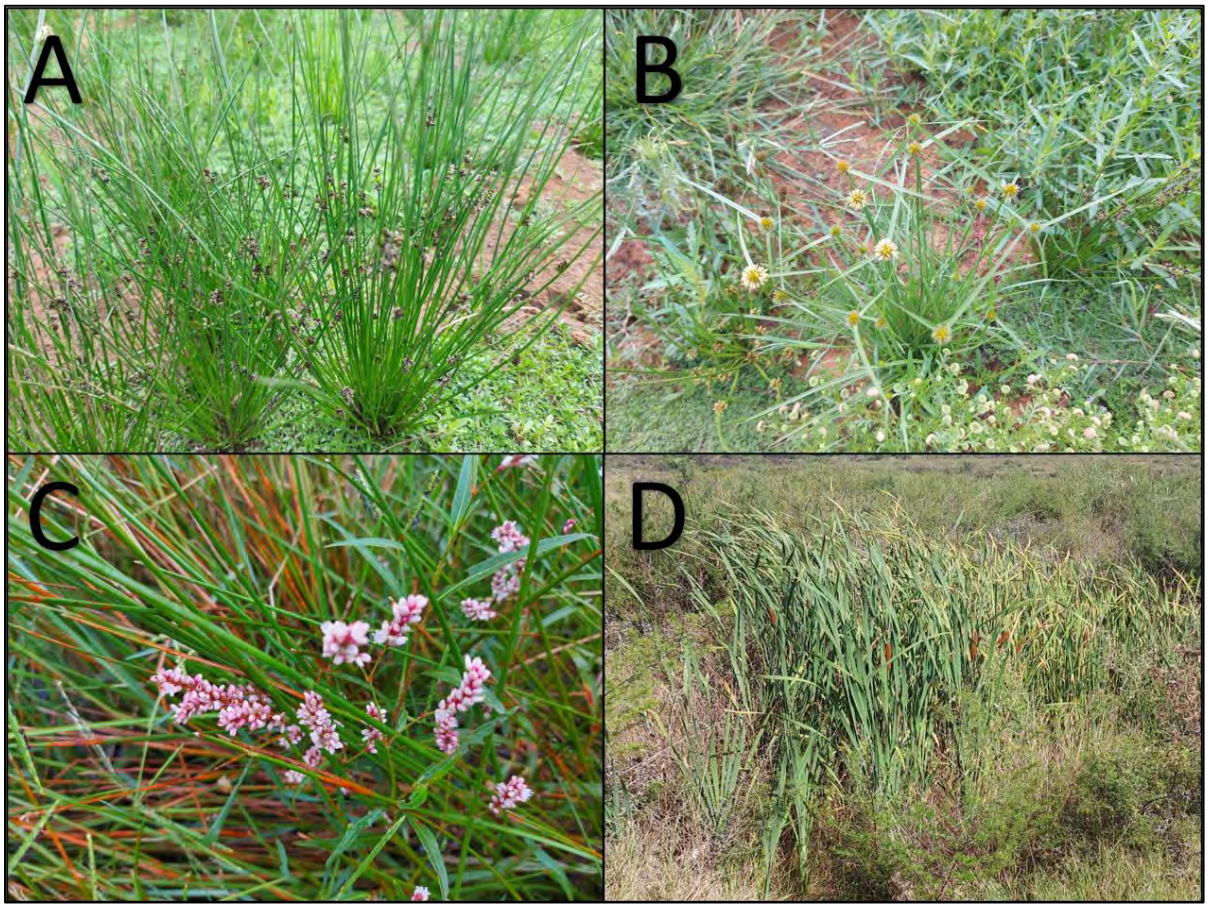


Figure 6-5: Hydrophytic vegetation identified within delineated watercourses. A) Cyperus spp. B) Kyllinga brevifolia C) Persicaria spp. D) Typha Capensis

6.1.4 General Functional Description of Wetland Types

Channelled valley bottom wetlands tend to contribute less to sediment trapping and flood attenuation than other systems. Channelled valley bottom wetlands are well known to improve the assimilation of toxicants, nitrates and sulphates, especially in cases where sub-surface flows contribute to the system's water source (Kotze *et al*., 2009).

The generally impermeable nature of depressions and their inward draining features are the main reasons why the streamflow regulation ability of these systems is mediocre. Regardless of the nature of depressions in regard to trapping all sediments entering the system, sediment trapping is another Eco Service that is not deemed as one of the essential services provided by depressions, even though some systems might contribute to a lesser extent. The reason for this phenomenon is due to winds picking up sediments within pans during dry seasons which ultimately leads to the removal of these

sediments and the deposition thereof elsewhere. The assimilation of nitrates, toxicants and sulphates are some of the higher rated Eco Services of depressions. This latter statement can be explained by the precipitation, as well as continued precipitation and dissolving of minerals and other contaminants during dry and wet seasons, respectively (Kotze *et al*., 2009).

Hillslope seeps are well documented by Kotze *et al*. (2009) to be associated with sub-surface ground water flows. These systems tend to contribute to flood attenuation given their diffused nature. This attenuation only occurs while the soil within the wetland is not yet fully saturated. The accumulation of organic material and sediments contributes to prolonged levels of saturation due to this deposition slowing down the sub-surface movement of water. Water typically accumulates in the upper slope (above the seep). The accumulation of organic matter additionally is essential in the denitrification process involved with nitrate assimilation. Seeps generally also improve the quality of water by removing excess nutrient and inorganic pollutants originating from agricultural, industrial, or mining activities. The diffuse nature of flows ensures the assimilation of nitrates, toxicants and phosphates with erosion control being one of the Eco Services provided by the wetland given the nature of a typical seep's position on slopes.

Unchannelled valley bottoms are characterised by sediment deposition, a gentle gradient with streamflow generally being spread diffusely across the wetland, ultimately ensuring prolonged saturation levels and high levels of organic matter. The assimilation of toxicants, nitrates and phosphates is usually high for unchannelled valley-bottom wetlands, especially in cases where the valley is fed by sub-surface interflow from slopes. The shallow depths of surface water within this system adds to the degradation of toxic contaminants by means of sunlight penetration.

It is however important to note that the descriptions of the above-mentioned functions are merely typical expectations. All wetland systems are unique and therefore, the ecosystem services rated high for these systems on site might differ slightly to those expectations. A composite wetland delineation map is presented for each of the five Harmony Free State Operations in Figure 6-6, Figure 6-7, Figure 6-8, Figure 6-9 and Figure 6-10.

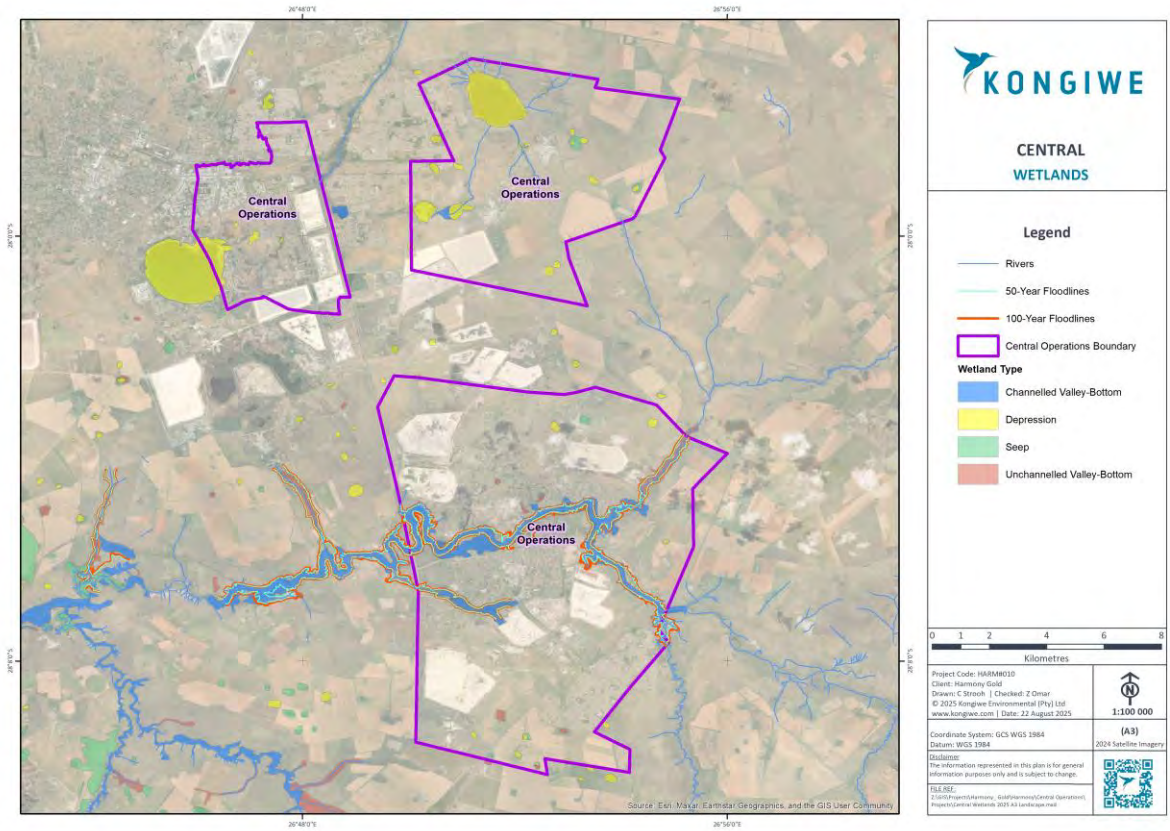


Figure 6-6: Composite wetland delineation map for the Central Operations

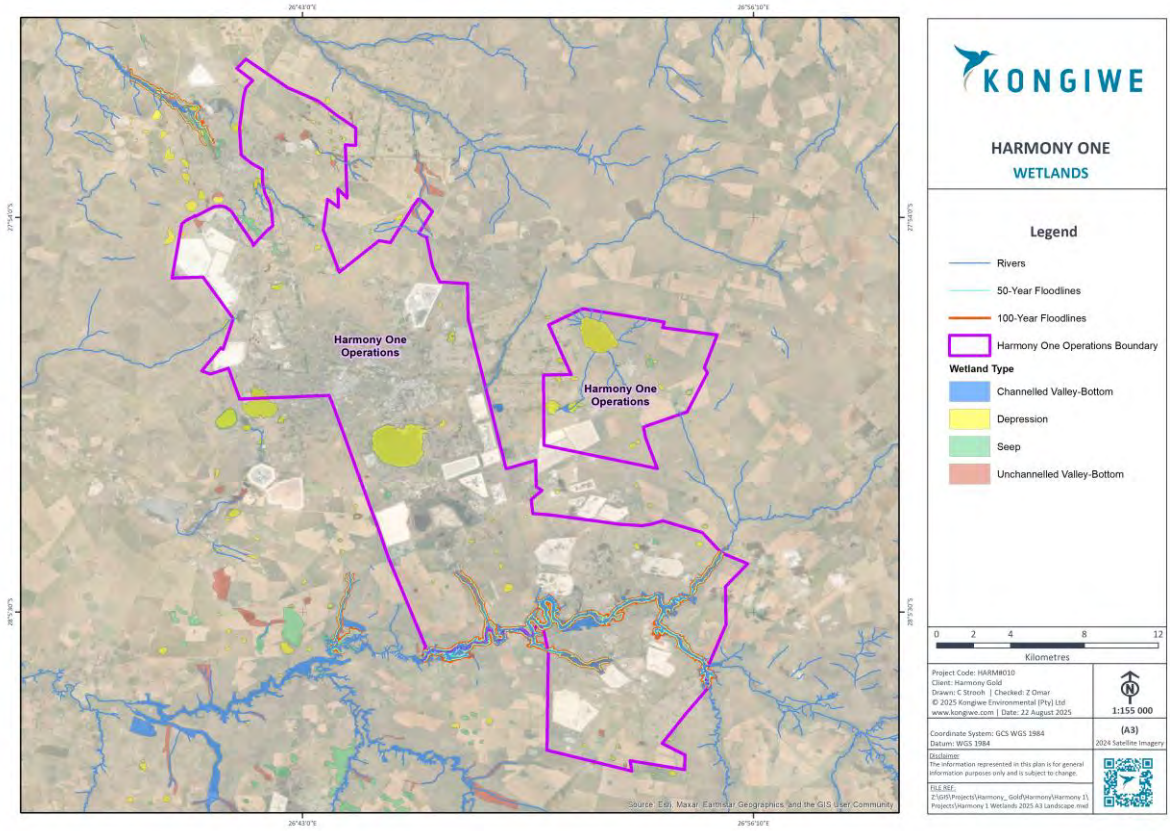


Figure 6-7: Composite wetland delineation map for the Harmony One Operations

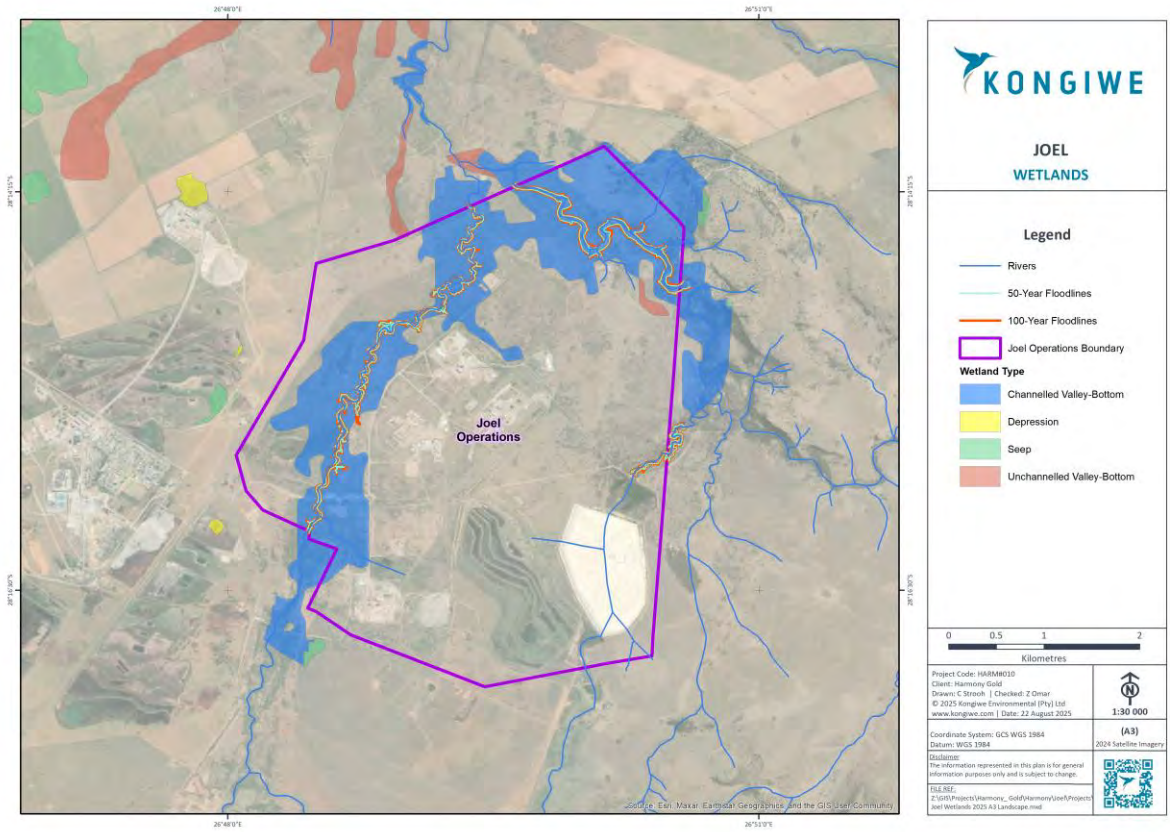


Figure 6-8: Composite wetland delineation map for the Joel Operations

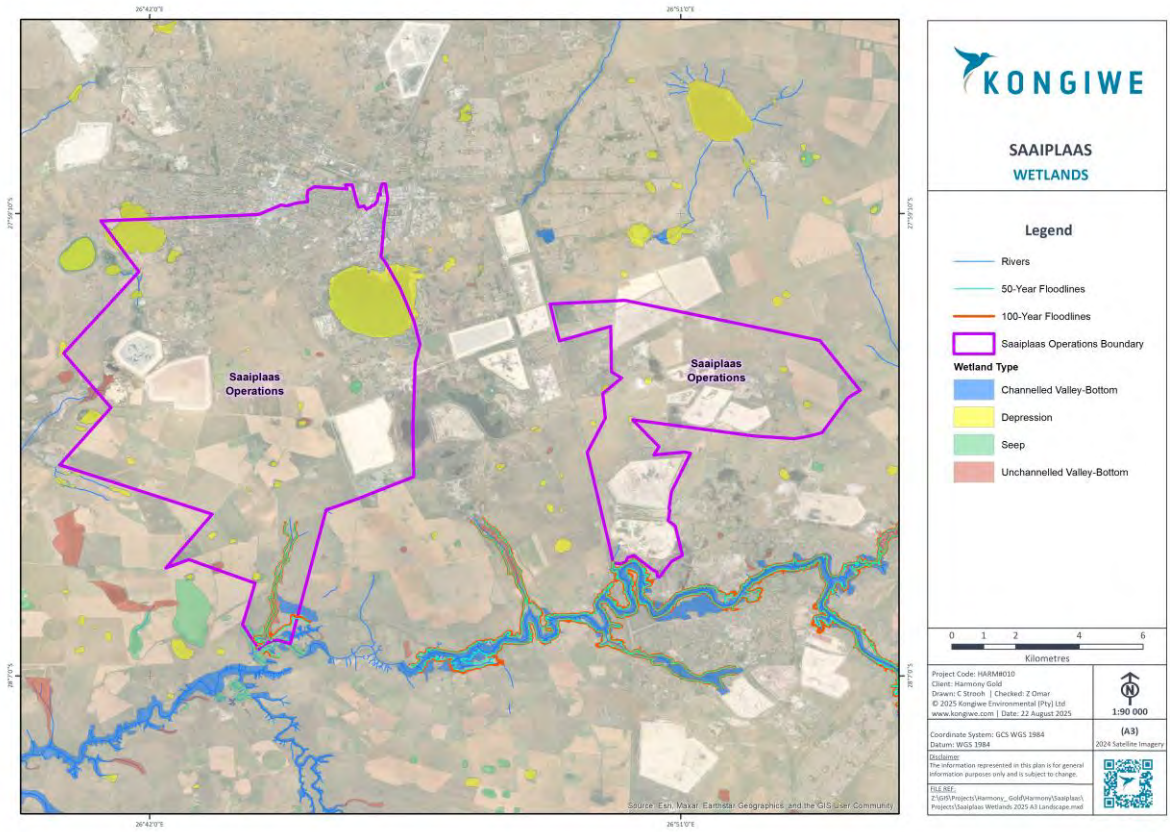


Figure 6-9: Composite wetland delineation map for the Saaiplaas Operations

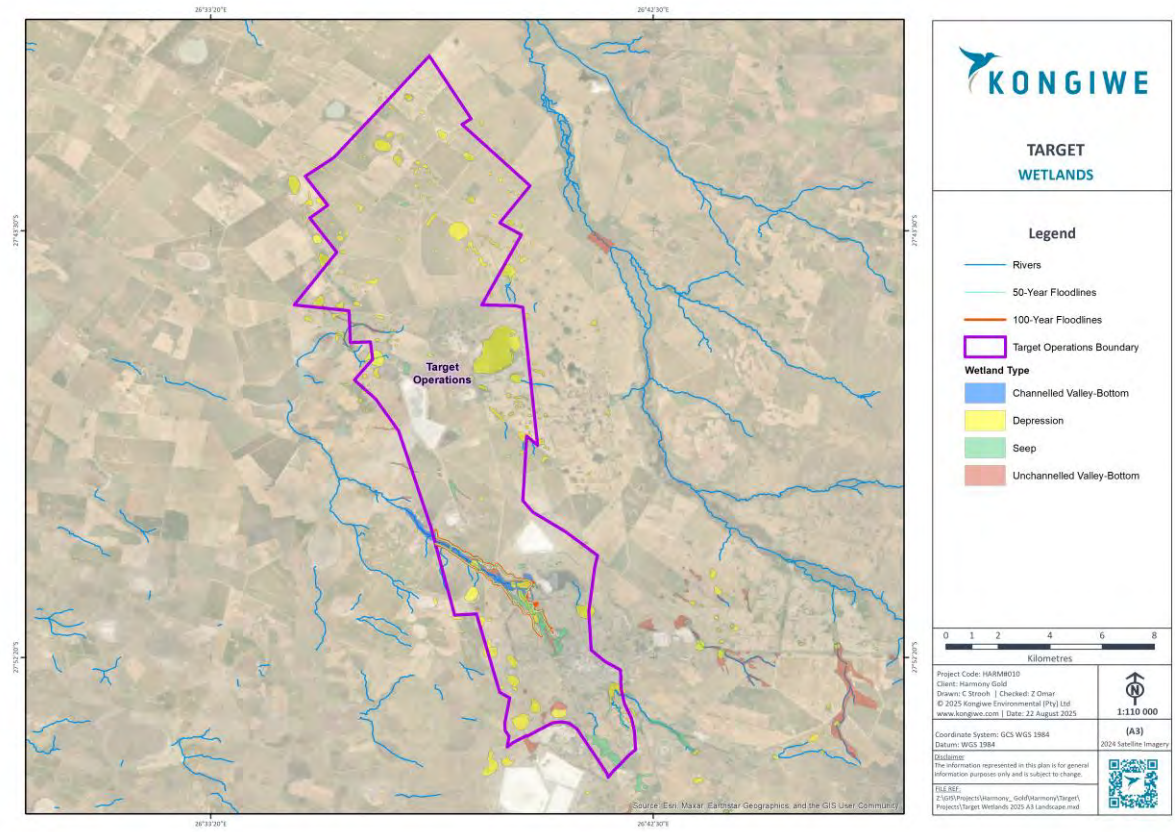


Figure 6-10: Composite wetland delineation map for the Target Operations

6.2 Aquatics Assessment

6.2.1 *In situ* water quality

In situ water quality analysis was conducted at all sites assessed that presented adequate surface water during the low flow survey. These results are important to assist in the interpretation of biological results due to the direct influence water quality has on aquatic life forms. Water quality limits were compared to water quality standards provided by DWAF (1996) and the RQOs for the Middle Vaal per relevant catchment and therefore vary between rivers and operations. Water quality results were divided according to the operation which they pertain to.

6.2.1.1 Central Operations

The results of the low flow survey for Central Operations are presented in Table 6-1. An illustration of each site and its associated pH and EC as well as the direction of flow has been presented in Figure 6-11 and Figure 6-12, respectively for a special understanding of the complexities of the water quality associated with the Central Operations. Yellow arrows indicate compliant water quality parameters and red indicate non-compliant parameters.

Table 6-1: In situ water quality results for the Central Operations (May 2022)

Site	Watercourse Type	pH	Conductivity (µS/cm)	DO (mg/l)	Temperature (°C)
TWQR*		6.5-9.0	*	>5.00	5-30
Rietspruit River					
RQO		6.5 – 9.2	≤ 850	*	*
SVC 03	River	8.44	1581	5.60	19.10

New CP ESW	River	8.24	1781	8.35	15.30
Merriespruit River					
RQO		6.5 – 8.5	≤ 650	*	*
SVC 14	River	8.24	712	5.90	17.40
Sand River					
RQO		6.5 – 9.2	≤ 850	*	*
SVC 01	River	7.92	261	2.50	18.30
ESW 55	River	8.08	659	6.80	19.30
SVC 10/Mostert 12/ ESW 54	River	7.85	2130	3.40	16.30
SVC 11	River	8.03	506	1.20	15.00
SVC 08	River	6.29	1140	5.70	16.20
Doring River					
RQO		7.5 – 9.2	≤ 700	*	*
SVC 05	River	8.44	1986	6.53	12.50
ESW TK1	River	No Access			
SVC 07	River	7.34	2830	7.01	15.20
Bosluisspruit River					
RQO		7.5 – 9.2	≤ 700	*	*
SVC 06	River	6.41	3930	8.10	9.90

Levels exceeding recommended guideline levels are indicated in red,* No limit prescribed by relevant legislation

Water quality data was assessed in five main stem rivers for the Central Operations as outlined in Table 5 1. According to the water quality of the Rietspruit River reach, the reach was modified based on elevated EC in the reach and associated tributaries all above the RQO limit (≤ 850 µS/cm). The reach experienced an increase in EC from site SVC 03 (1581 µS/cm) which is upstream of the operations to site New CP ESW (1781 µS/cm) – both of which were measured above the RQO for the reach (≤ 850 µS/cm). The Merriespruit River reach assessed by site SVC 14 is considered compliant as all measured parameters are within both Target Water Quality Range (TWQR) and RQO limits. This site is upstream of the Central Operations and flows into the Sand River. The Sand River flows through the centre of the Central Operations dividing the property into two.

Water quality in the Sand River and associated tributaries indicated modified conditions with a pH or EC measured outside of either/both the TWQR and/or RQO. The upstream site at SVC 01 indicates Dissolved Oxygen (DO) (2.50 mg/l) below the TWQR of >5.00 mg/l. The midstream site of SVC 11 also presented DO (2.50 mg/l) below the TWQR of >5.00 mg/l. Site SVC 08 is the downstream site which is below the confluence of the Sand River and the Doring River. Water quality at SVC 08 indicated modified conditions with the pH below the TWQR and RQO (6.29) for the reach (6.5) and the EC elevated (1140 µS/cm) above the RQO limit (≤ 850 µS/cm). The EC in the Sand River indicates a steady increase in a downstream direction with site ESW 84 and SVC 10/Mostert 12/ ESW 54 presenting potential sources of modification with a measured EC of 12260 µS/cm and 2130 µS/cm respectively, which both flow from upstream mining activity.

Another source of the elevated EC is the Doring River which has elevated EC above RQO limits (≤ 700 µS/cm) at sites SVC 05 (1986 µS/cm) and SVC 07 (2830 µS/cm). The recorded pH observed at SVC 07 of 7.34 was also below the RQO limit of 7.5 but above the TWQR limit of 6.5. This system also observes a downstream increase in EC with the Bosluisspruit River flowing into the reach, a potential source of modification as the EC of the river as measured at SVC 06 (3930 µS/cm) is elevated above the RQO (≤ 700 µS/cm) for the reach as well as measured values in the Doring. pH levels within the

Bosluisspruit River are considered acidic in nature with a concentration of 6.41 which is below the RQO limit of 7.5 as well as the TWQR limit of 6.5.

Overall comments

The Sand River which flows through the Central Operations is compliant upstream of the operations with low EC concentrations and a neutral pH. Sources of modification to the system include the Rietspruit reach with elevated EC, Sites SVC 10/Mostert 12/ ESW 54 which indicate direct influence on the Sand River reach as measured by SVC 11 observed by an increase in EC and pH as well as the Doring River which represents modification from downstream mining activity. As a result, the downstream site SVC 08 represents modification with elevated salts and acidic pH, indicating modification. Water quality within all systems within the project area bar the Merriespruit River are considered to be a limiting factor for aquatic biodiversity due to elevated EC and diminished DO across the operations.

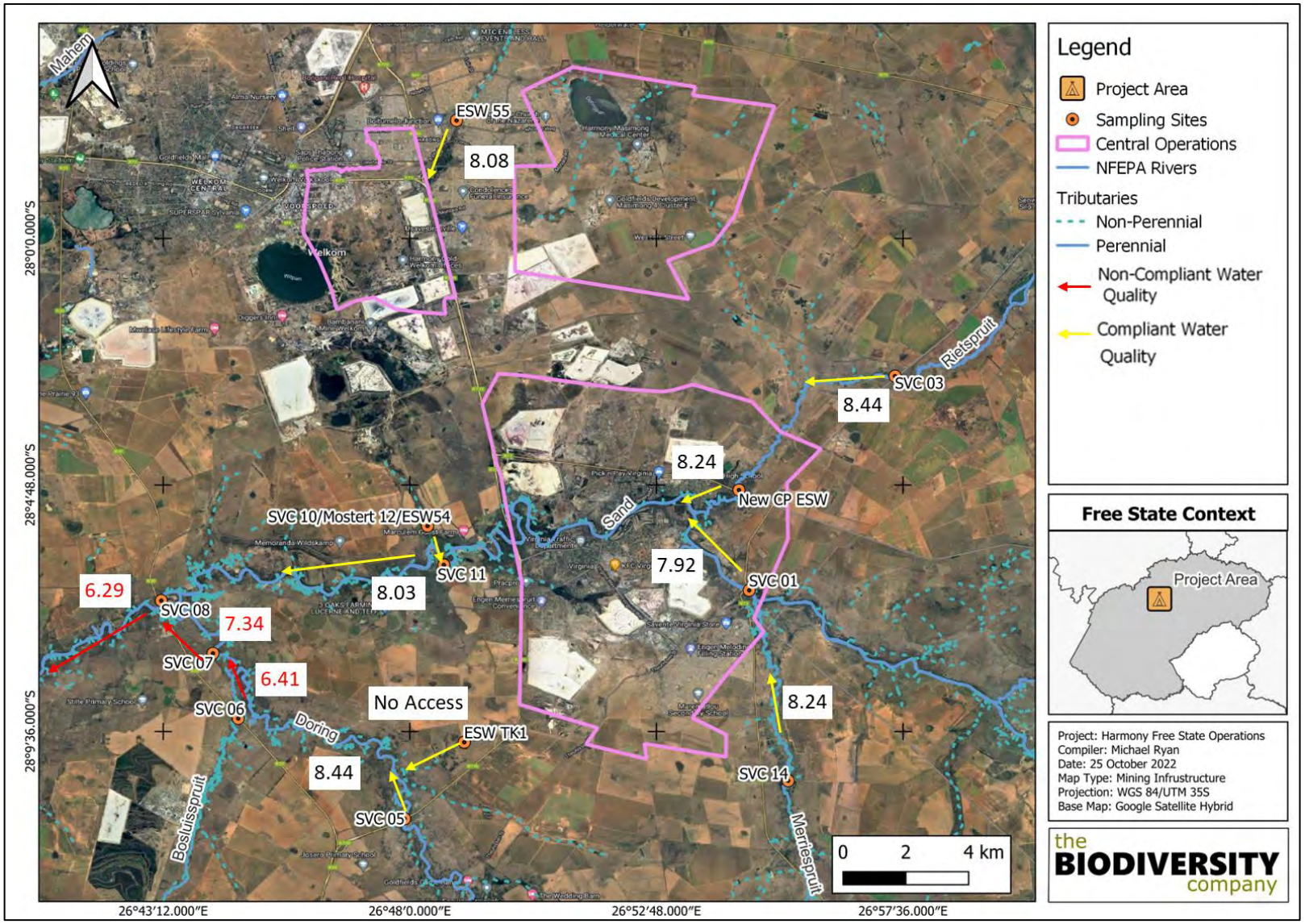


Figure 6-11: pH of each site associated with the Central Operations

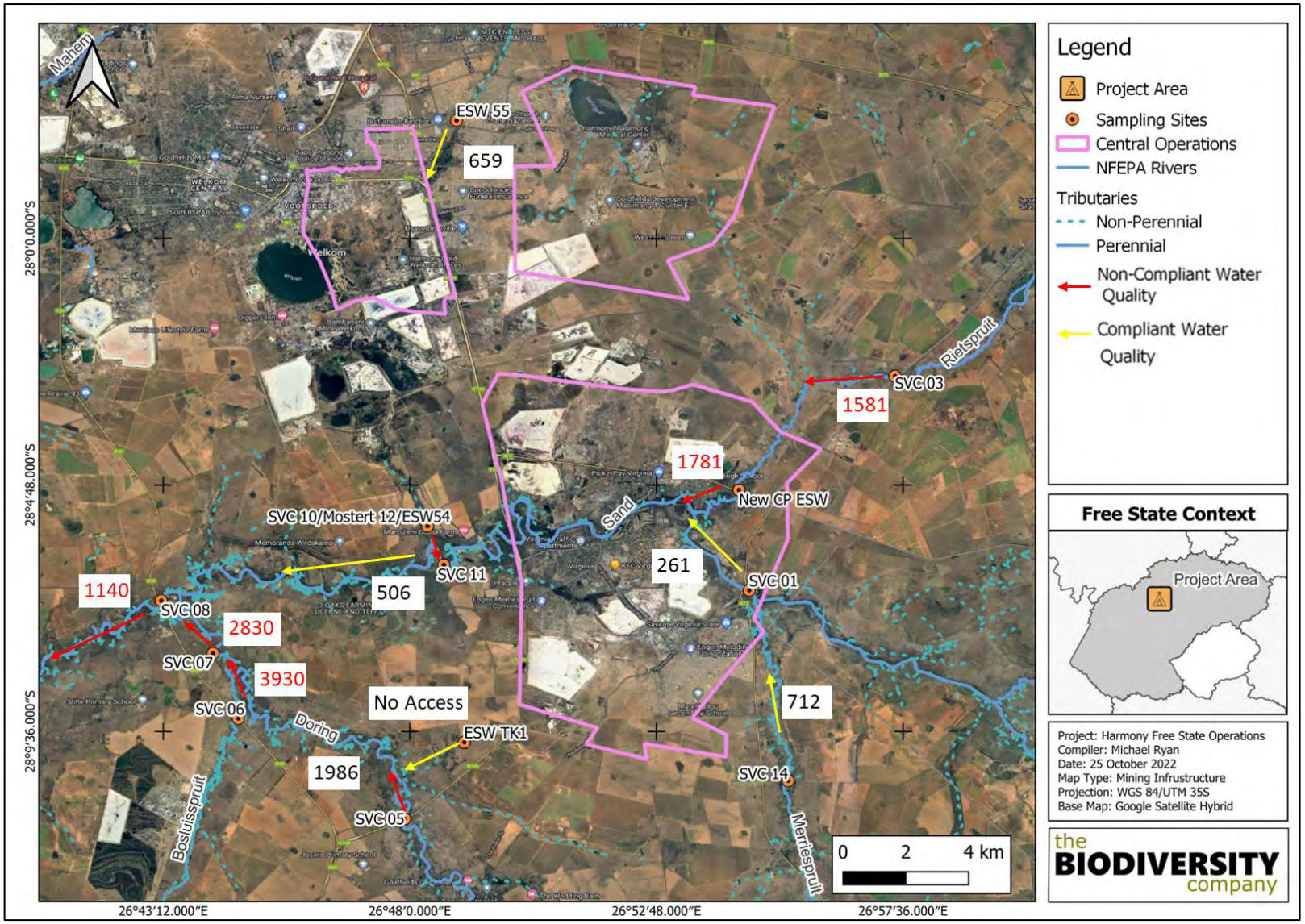


Figure 6-12: EC of each site associated with the Central Operation

6.2.1.2 Harmony One Operations

The results of the low flow survey for Harmony One Operations are presented in Table 6-2. An illustration of each site and its associated pH and EC as well as the direction of flow has been presented in Figure 6-13 and Figure 6-14, respectively for a special understanding of the complexities of the water quality associated with the Harmony One Operations. Yellow arrows indicate compliant water quality parameters and red indicate non-compliant parameters.

Table 6-2: In situ water quality results for the Harmony One Operations (May 2022)

Site	Watercourse type	pH	Conductivity (µS/cm)	DO (mg/l)	Temperature (°C)
TWQR*		6.5-9.0		>5.00	5-30
Rietspruit River					
RQO		6.5 – 9.2	≤ 850	*	*
SVC 03	River	8.44	1581	5.60	19.10
New CP ESW	River	8.24	1781	8.35	15.30
Sand River					
RQO		6.5 – 9.2	≤ 850	*	*
SVC 01	River	7.92	261	2.50	18.30
ESW 85	Instream Dam	7.40	1663	4.12	15.60
ESW 55	River	8.08	659	6.80	19.30
SVC 10/Mostert 12/ ESW 54	River	7.85	2130	3.40	16.30
SVC 08	River	6.29	1140	5.70	16.20
Mahem River					
RQO		6.5 – 8.5	≤ 700	*	*
ESW 17	Instream Dam	8.77	12710	7.50	17.80
ESW 14	Wetland	7.63	5400	3.80	17.80
Mahem 4B	Instream Dam	No Access			
ESW 100	Dam/Pan	7.12	5980	4.50	16.90
Sandspruit River					
RQO		6.5 – 8.5	≤ 700	*	*
SVC 15	River	8.61	1482	6.73	13.90
SVC 16	River	8.19	1504	5.00	18.2
ESW 6	River	7.52	1512	5.60	14.6

Levels exceeding recommended guideline levels are indicated in red, * No limit prescribed by relevant legislation

The Harmony One Operation has the largest spatial footprint of the Harmony Free State Operations. Water quality data was assessed in four main stem rivers for the Harmony Operation as outlined in Table 6-2. The large footprint has the potential to affect the southern systems which flow into the Vet River; the Sandspruit which flows into the Vaal River and the Mahem River which no longer has continuity with other river systems. According to the water quality of the Rietspruit River reach, the reach was modified based on elevated EC and associated tributaries all above the RQO limit (≤ 850 µS/cm). The reach experienced an increase in EC from site SVC 03 (1581 µS/cm), which is upstream of the operations, to site New CP ESW (1781 µS/cm). The upslope unlined pollution control dam (PCD) below a Tailings Storage Facility (TSF) is identified as a potential source of elevated EC however, this requires

further investigation to confirm. The Rietspruit River flows into the Sand River which flows through the southern section of the Harmony One Operations.

Water quality in the Sand River and associated tributaries indicated modified conditions with a minimum of one or two parameters measured outside of either/both the TWQRs and/or RQOs. The upstream site at SVC 01 indicates Dissolved Oxygen (DO) (2.50 mg/l) below the TWQR of >5.00 mg/l. Site SVC 08 is the downstream site which is below the confluence of the Sand River and the Doring River. Water quality at SVC 08 indicated modified conditions with the pH (6.29) below the TWQR and RQO for the reach (6.5) and the EC elevated (1140 µS/cm) above the RQO limit (≤ 850 µS/cm). The EC in the Sand River indicates a steady increase in a downstream with sites ESW 85 and SVC 10/Mostert 12/ ESW 54 presenting potential sources with measured EC of 12260 µS/cm and 2130 µS/cm, respectively, which both flow from upstream mining activity. North of these tributaries are multiple waterbodies and watercourses that don't show proper connectivity; however, are assumed to flow south towards site SVC 10/Mostert 12/ ESW 54.

The source of the Mahem River is in the western section of the Harmony One Operations. Two tributaries flow into this reach. The first is in the north which has two separate reaches which have their confluence at Mahem 4B. The second flows into the Mahem River further downstream. The first tributary is comprised of sites ESW 17 and ESW 14. Both sites are marked with elevated EC above the ≤ 700 µS/cm RQO at 12710 µS/cm and 5400 µS/cm. The elevated EC at ESW 17 is 1815 times the prescribed RQO, with a potential source of modification to the reach identified as the Elands mining operations to the east. The system decreases in concentration of EC in a downstream direction to ESW 14. Site ESW 14 was also marked by depressed DO concentrations of 3.80 mg/l which is a wetland system with no observed surface flow which is suggested to account for the depleted DO. The second tributary consists of site ESW 100. Site ESW 100 has a depleted DO of 4.50 mg/l which is also a standing body of water. ESW 100 is downstream of multiple PCDs which are associated with the St. Helena TSF that accounts for the elevated EC at both sites of 1731 µS/cm and 5980 µS/cm, respectively.

The Sandspruit River in the north of the project area is comprised of the main reach and one tributary which flows into the Sandspruit far downstream below site SVC17, after flowing through the Target Operations. For the Harmony One Operations site, SVC 15 represents an upstream site and SVC 16 a downstream site. Based on these sites, the Sandspruit was considered modified as some measured parameters were outside TWQR and RQO limits for the reach. Site SVC 15 had an elevated EC of 1482 µS/cm above the RQO limit of ≤ 700 µS/cm and an elevated pH of 8.61 above the TWQR, as well as a RQO limit of 8.5. SVC 16 was found with an elevated EC of 1502 µS/cm. The pH decreases in a downstream direction while the EC increases, however these changes are considered negligible. The tributary contains site ESW 6 which was observed to have elevated EC of1512 µS/cm above the ≤ 700 µS/cm RQO limit. Site ESW 6 is related to the Freddies WRD which are potential sources for the observed modification.

Overall comments

The Sand River which flows through the southern section of the Harmony One Operations is compliant upstream of the operations with low EC concentrations and a neutral pH. Sources of modification to the system include the Rietspruit reach with elevated EC likely influenced by the associated PCD and TSF, Sites SVC 10/Mostert 12/ ESW 54 which indicate direct influence on the Sand River reach from upstream mining activity. As a result, the downstream site SVC 08 represents modification with elevated salts and acidic pH, indicating modification. The Mahem River experiences elevated EC concentrations throughout and therefore modification results from the Elands mining operations. The Sandspruit River had elevated EC and pH concentrations upstream of the mining operations with negligible change recorded downstream. Likely sources include agriculture and malfunctioning WWTW discharging effluent further upstream but locating the source of modification is outside the scope of this report. The Sandspruit tributary experienced elevated EC and pH throughout bar the pH at ESW 6 and therefore indicates modification from the Tshepong waste rock dump and associated mining activity. Water quality

within all systems within the project area are considered to be a limiting factor for aquatic biodiversity due to elevated EC and diminished DO across the operations.

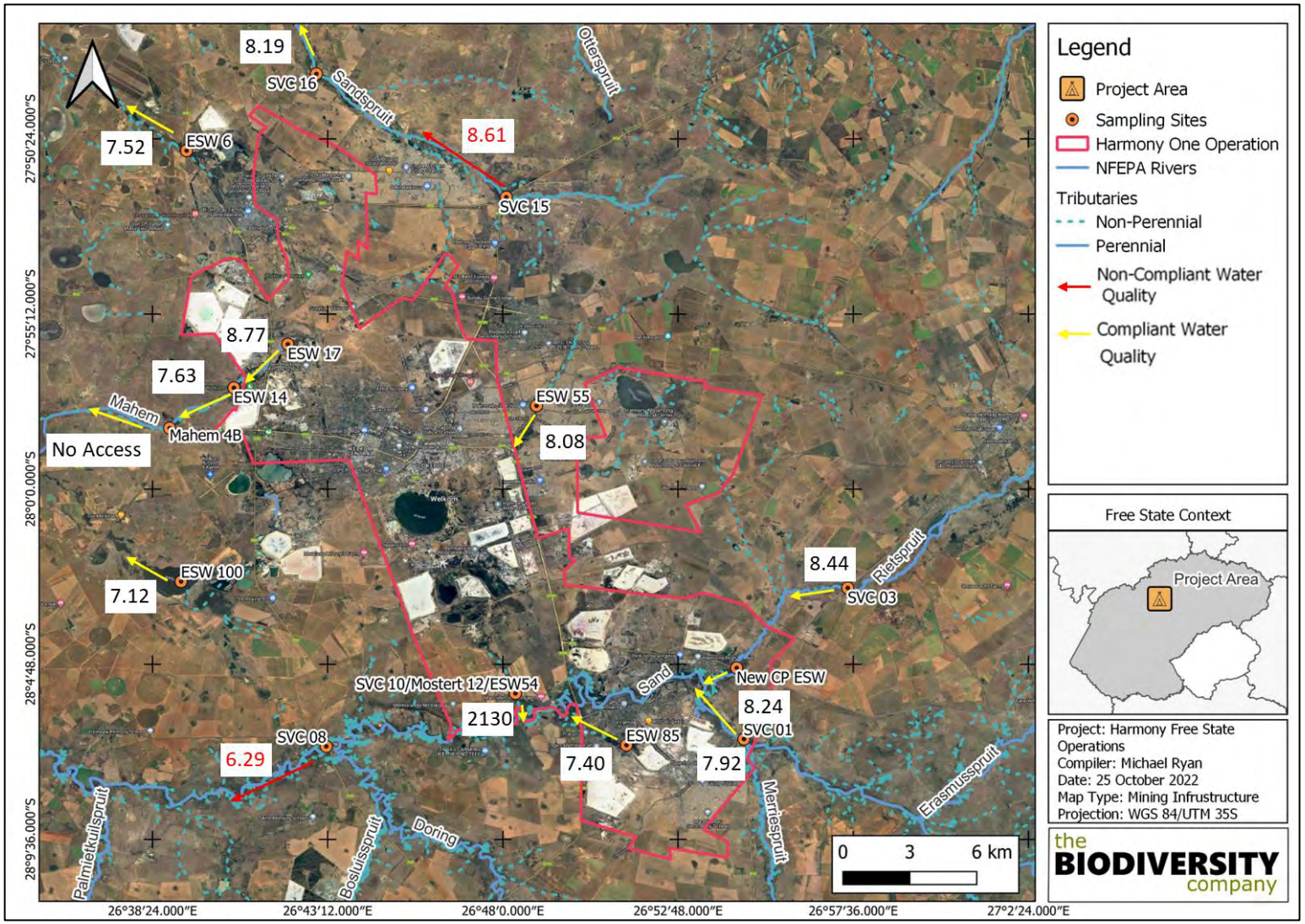


Figure 6-13: pH of each site associated with the Harmony One Operations

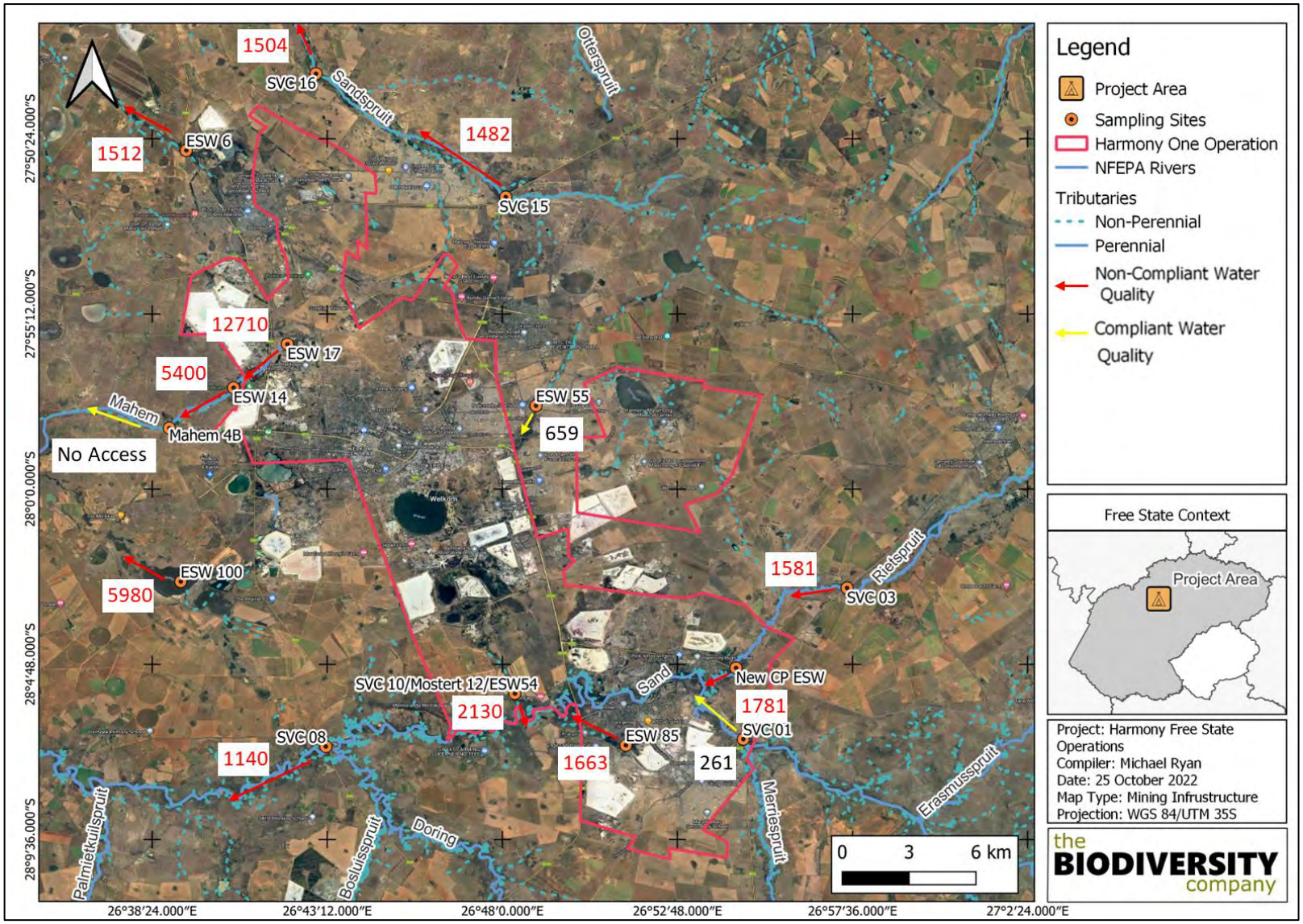


Figure 6-14: EC of each site associated with the Harmony One Operations

6.2.1.3 Joel Operations

The results of the low flow survey for Joel Operations are presented in Table 6-4. An illustration of each site and its associated pH and EC as well as the direction of flow has been presented in Figure 6-15 and Figure 6-16, respectively for a special understanding of the complexities of the water quality associated with the Joel Operations. Yellow arrows indicate compliant water quality parameters and red indicate non-compliant parameters.

Table 6-3: In situ water quality results for the Joel Operations (May 2022)

Site	Watercourse Type	pH	Conductivity (µS/cm)	DO (mg/l)	Temperature (°C)
TWQR		6.5-9.0	-	>5.00	5-30
Doring River					
RQO		7.5 – 9.2	≤ 700	*	*
SVC 12	River	No Access			
ESW 71	River	DRY			
ESW 82	River	7.78	580	7.30	19.8
ESW 65	River	8.94	1170	4.73	13.70
SVC 04	River	7.80	4110	6.70	13.2
SVC 05	River	8.44	1986	6.53	12.50
Theronspruit River					
RQO		7.5 – 9.2	≤ 700	*	*
ESW 79	River	No Access			
ESW 80	River	7.71	7440	4.81	13.1

Levels exceeding recommended guideline levels are indicated in red, * No limit prescribed by relevant legislation

Water quality data was assessed in one main stem river and one of its tributaries for the Joel Operations as outlined in Table 6-3. The main stem river is the Doring River which follows the north and eastern boundaries of the operation, while the associated tributary known as the Theronspruit River follows the western boundary of the operation. The Doring River consists of sites ESW 82 upstream of the operation which is considered natural as all measured parameters are within the prescribed TWQR and RQO limits. Site SVC 04 is a downstream site for the Doring River after the confluence with the Theronspruit River. The EC was elevated over the RQO limit ≤ 700 µS/cm limit at 4110 µS/cm. Site SVC 05 is a far downstream site and also had an elevated EC of 1986 µS/cm with the decreased concentration of dissolved solids suggested as a result of dilution with multiple tributaries entering between the two sites. The concentration difference between ESW 82 and SVC 04 is suggested to result from either the tributary which ESW 65 is situated along, which had an elevated EC of 1170 µS/cm and depleted DO at 4.73 mg/l which is below the TWQR limit of 5.0 mg/l, or the Theronspruit River. The source of the modification to the system along which ESW65 is located is unknown but outside of the scope of work for this report. The Theronspruit River is a more likely source as site ESW 80 which is associated to the Joel South Operations and the neighbouring Beatrix mine which had an elevated EC concentration of 7440 µS/cm, as well as a depleted DO concentration of 4.81 mg/l.

Overall comments

The pH throughout the watercourses associated with the Joel operation indicate compliant water quality based on the single parameter. The measured EC however indicates modification. Upstream of the Joel Operation water quality is compliant as measured at ESW 82; however, downstream conditions indicate modified conditions in the Doring River. Sources of modification include the tributary ESW 65 but the significant influence, as measured by ESW 80, is from the Theronspruit River which indicates

modification from the mining activity of the neighbouring Beatrix mine and Joel Operation. Water quality within the Doring River and Theronspruit River is considered to be a limiting factor for aquatic biodiversity due to elevated EC in both systems.

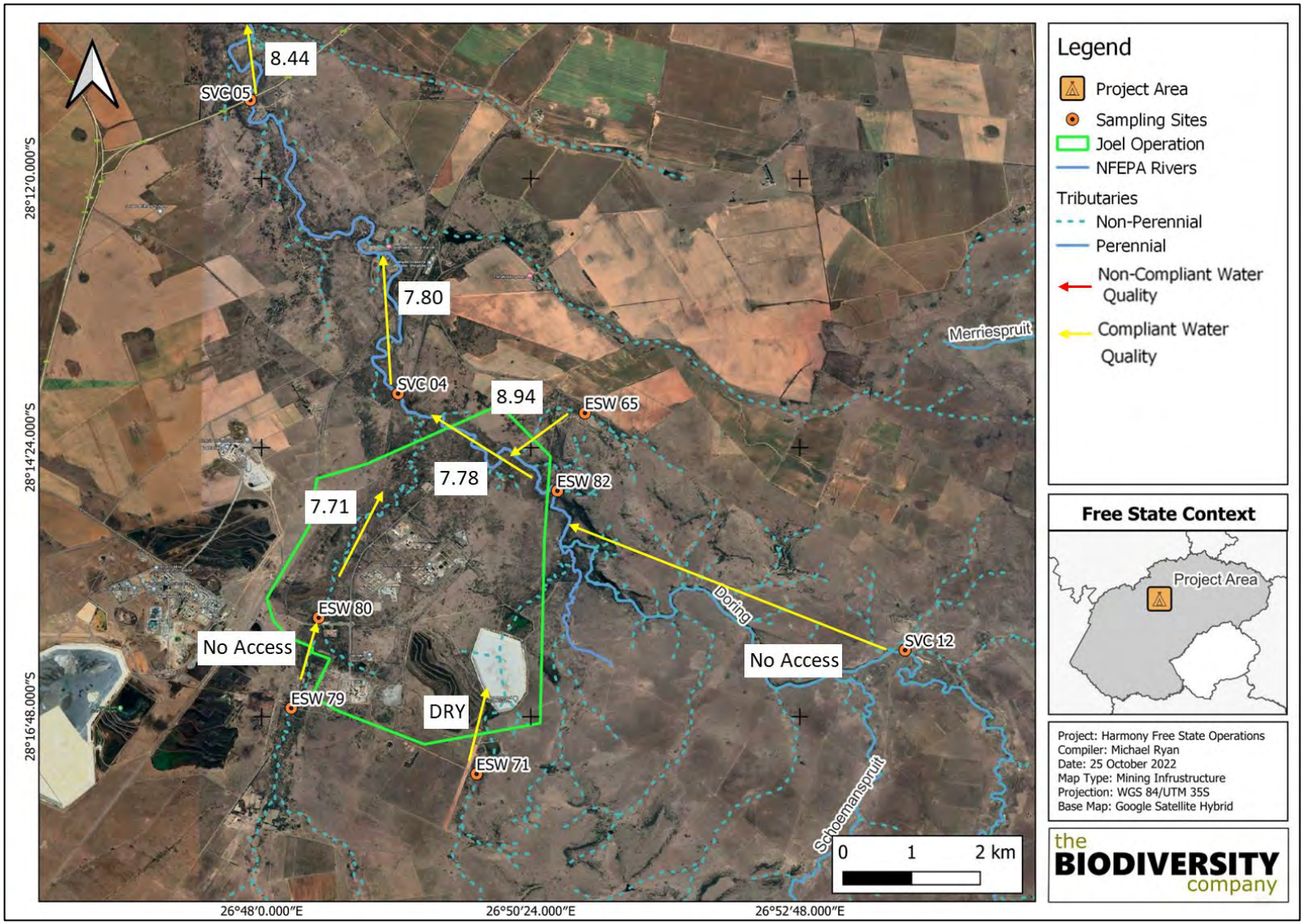


Figure 6-15: pH of each site associated with the Joel Operation

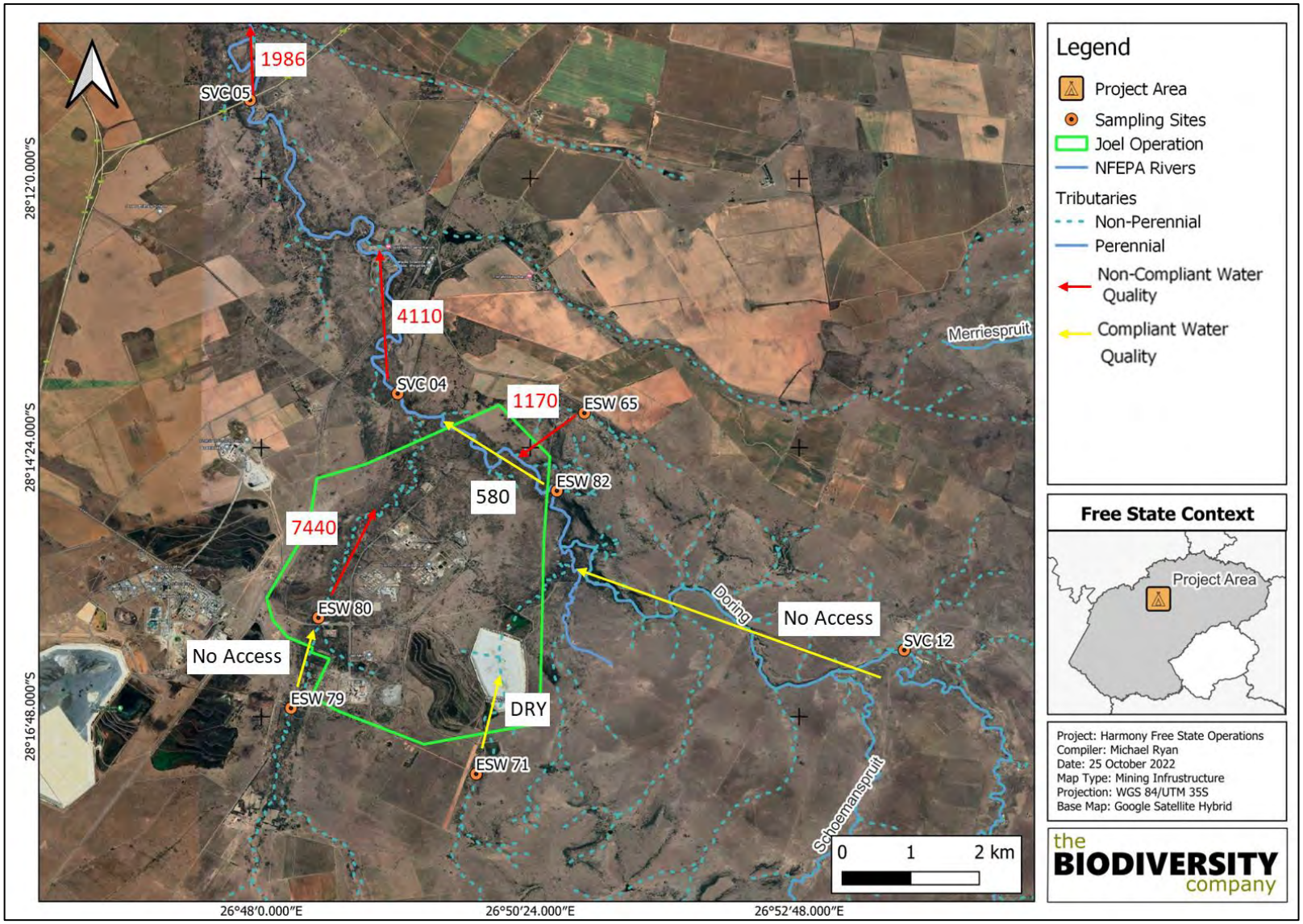


Figure 6-16: EC of each site associated with the Joel Operation

6.2.1.4 Saaiplaas Operations

The results of the low survey for Saaiplaas Operations are presented in Table 6-4. An illustration of each site and its associated pH and EC, as well as the direction of flow has been presented in Figure 6-17 and Figure 6-18, respectively, to give special understanding of the complexities of the water quality associated with the Saaiplaas Operations. Yellow arrows indicate compliant water quality parameters and red ones indicate non-compliant parameters.

Table 6-4: In situ water quality results for the low flow survey (May 2022)

Site	Watercourse Type	pH	Conductivity (µS/cm)	DO (mg/l)	Temperature (°C)
TWQR*		6.5-9.0		>5.00	5-30
Rietspruit River					
RQO		6.5 – 9.2	≤ 850	*	*
SVC 03	River	8.44	1581	5.60	19.10
Sand River					
RQO		6.5 – 9.2	≤ 850	*	*
SVC 11	River	8.03	506	1.20	15.00
ESW 98	River	8.39	2670	6.10	21.10
SVC 08	River	6.29	1140	5.70	16.20
Doring River					
RQO		7.5 – 9.2	≤ 700	*	*
SVC 07	River	7.34	2830	7.01	15.2
Mahem River					
RQO		6.5 – 8.5	≤ 700	*	*
ESW 73	Instream Dam	7.24	8840	6.10	16.00
ESW 101	Instream Dam	7.12	3120	5.60	17.10
ESW 100	Dam/Pan	7.12	5980	4.50	16.90

Levels exceeding recommended guideline levels are indicated in red, * No limit prescribed by relevant legislation

Water quality data was assessed in four main stem rivers for the Saaiplaas Operations as outlined in Table 6-4 . According to the water quality of the Rietspruit River reach, based on site SVC 03 which is upstream of the Saaiplaas Operations, the system is modified as it had elevated EC of 1581 µS/cm which was measured above the RQO for the reach (≤ 850 µS/cm). Identifying the source of this modification is outside the scope of this report with the site assessed to understand the extent of potential influence to the system from the Saaiplaas Operations. The Rietspruit River flows into the Sand River which flows to the south of the Saaiplaas Operation. Water quality in the Sand River and associated tributaries indicated modified conditions with a minimum of one or two parameters measured outside of either/both the TWQR and/or RQO. The upstream site for the western section of the operation is SVC 11 which presented DO concentrations of 2.50 mg/l which are below the TWQR of >5.00 mg/l. The concentrations of dissolved solids are below RQO limits at SVC 11, however, are above the RQO limit at the downstream site SVC 08. Site SVC 08 is the downstream site which is below the confluence of the Sand River and the Doring River. Water quality at SVC 08 indicated modified conditions with the pH below the TWQR and RQO (6.29) for the reach (6.5), and the EC elevated (1140 µS/cm) above the RQO limit

The EC in the Sand River indicates an increase in a downstream direction with site ESW 98 along tributaries which flow into the Sand River, a potential source of the increase in EC with an EC of 2670

µS/cm. Another potential source of the elevated EC is the Doring River which has elevated EC above RQO limits (≥ 700 µS/cm), at site SVC 07, with a concentration of 2830 µS/cm. The recorded pH observed at SVC 07 of 7.34 was also below the RQO limit of 7.5 but above the TWQR limit of 6.5.

The source of the Mahem River is in the western section of the Harmony One Operation. Two tributaries flow into this reach. The first is in the north and the second boarders the western boundary of the Saaiplaas Operation and has its confluence with the Mahem River further downstream. The second tributary consists of sites ESW 73, ESW 101 and ESW 100 which consist of multiple dams along the tributary. Site ESW 100 has depleted DO of 4.50 mg/l which is a standing body of water which accounts for the depleted DO concentrations. Sites ESW 73 and ESW 101 are instream dams associated with the St. Helena TSF that account for the elevated EC of 8840 µS/cm, 3120 µS/cm, respectively. ESW 100 is downstream of the multiple PCDs which are associated with the St. Helena TSF and account for the elevated EC of 5980 µS/cm.

Overall comments

The Sand River which flows to the south of the Saaiplaas Operation is compliant upstream of the operation with low EC concentrations and a neutral pH (SVC 01). Sources of modification to the system include the Rietspruit reach with elevated EC, Sites SVC 10/Mostert 12/ ESW 54 which experience modification from sites ESW45, ESW 35A and ESW 32. This indicates direct influence on the Sand River reach as measured by SVC 11 observed by an increase in EC and pH, as well as the Doring River which represents modification from downstream mining activity. As a result, the downstream site SVC 08 represents modification with elevated salts and acidic pH, indicating modification. The lower tributary of the Mahem River, which forms the western boundary of the Saaiplaas Operation, presented elevated EC throughout and indicates modification because of the St. Helena TSF and associated mining activities. Water quality within all systems of the project area is considered to be a limiting factor for aquatic biodiversity due to elevated EC and diminished DO across the operation.

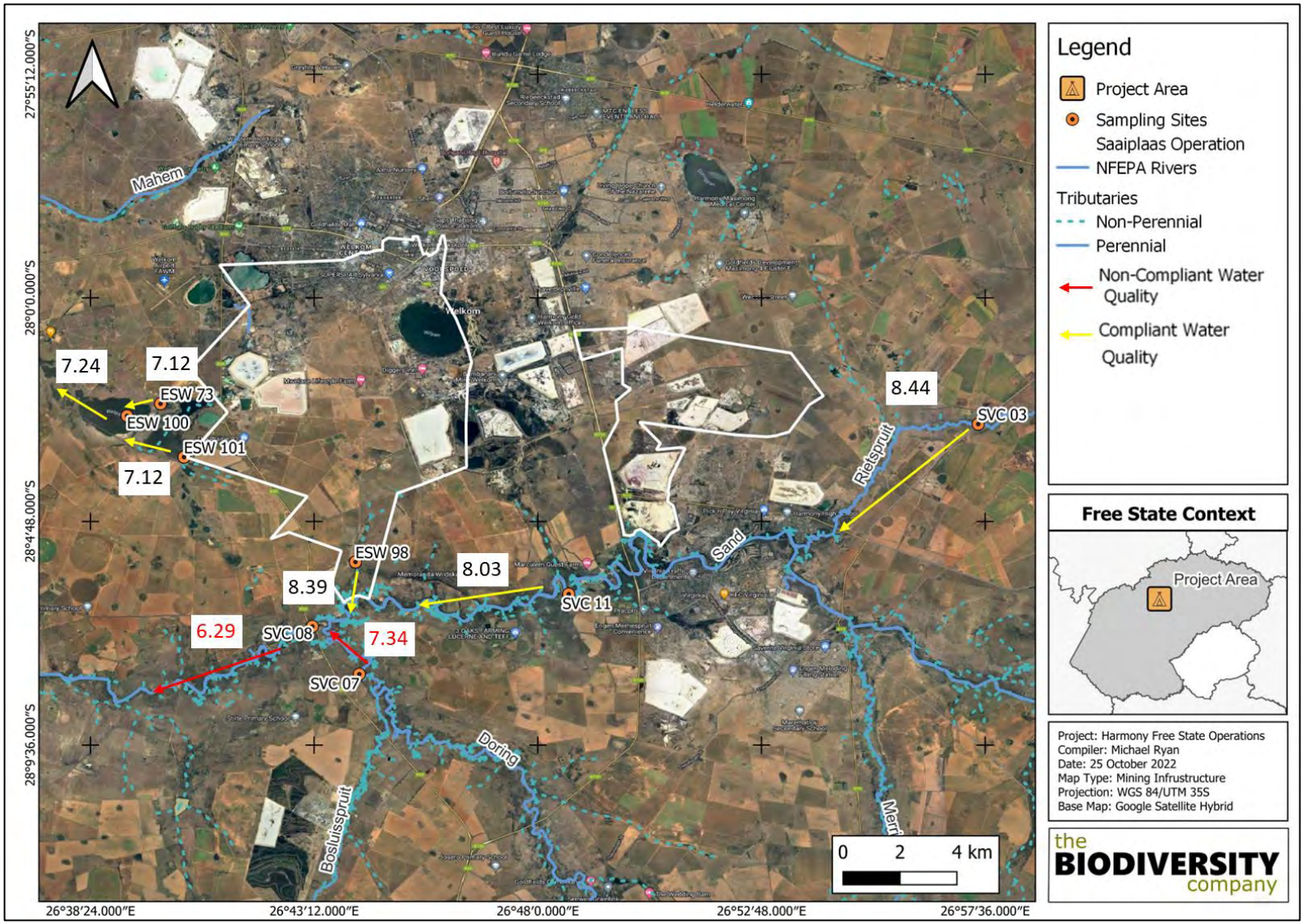


Figure 6-17: pH of each site associated with the Saaiplaas Operation

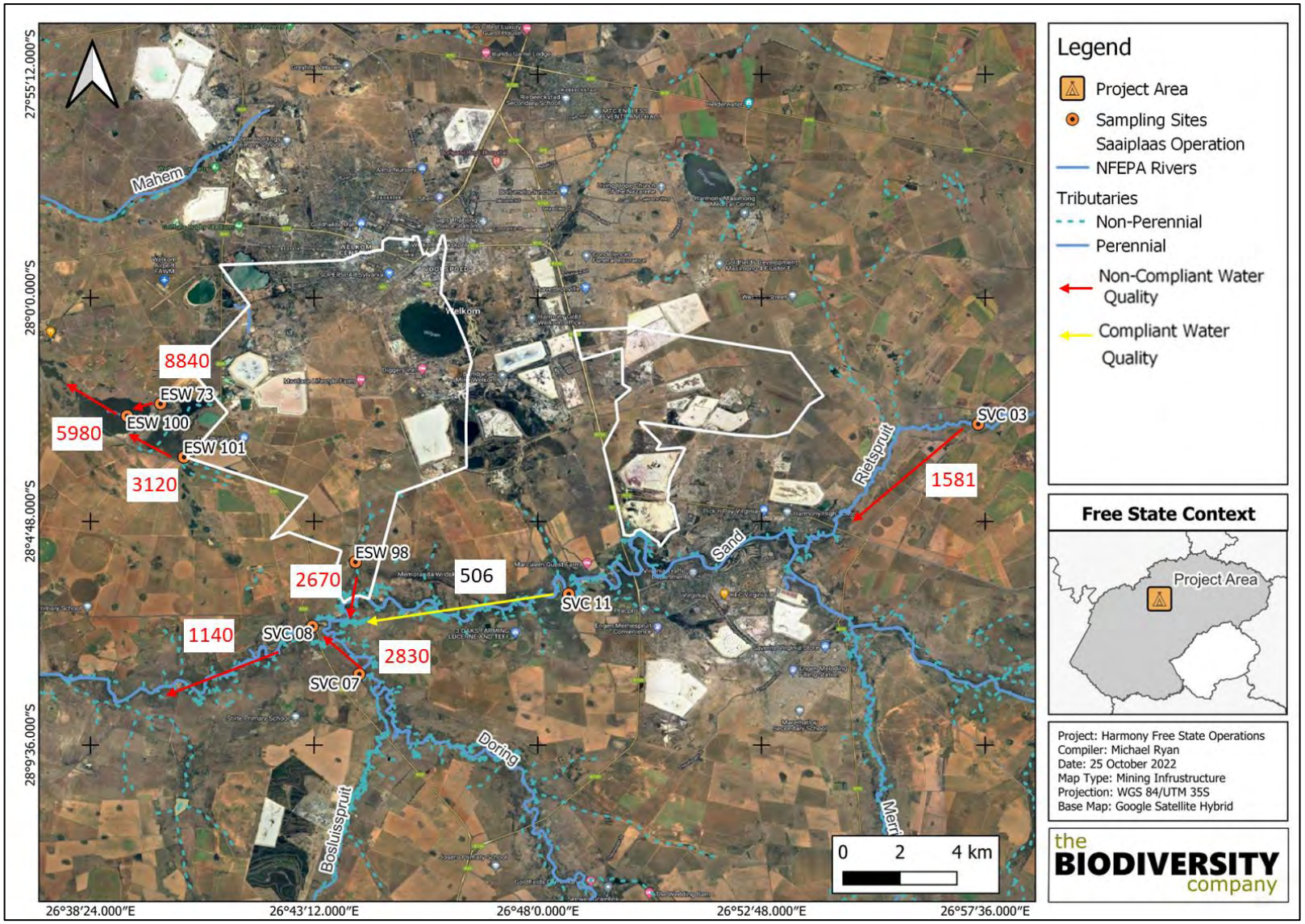


Figure 6-18: EC of each site associated with the Saaiplaas Operation

6.2.1.5 Target Operations

The results of the low flow survey for Target Operations are presented in Table 6-5. An illustration of each site and its associated pH and EC, as well as the direction of flow has been presented in Figure 6-19 and Figure 6-20, respectively. This provides a special understanding of the complexities of the water quality associated with the Target Operations. Yellow arrows indicate compliant water quality parameters and red ones indicate non-compliant parameters.

Table 6-5: In situ water quality results for the Target Operations (May 2022)

Site		pH	Conductivity (µS/cm)	DO (mg/l)	Temperature (°C)
TWQR*		6.5-9.0	-	>5.00	5-30
Sandspruit River					
RQO		6.5 – 8.5	≤ 700	*	*
SVC 15	River	8.61	1 482	6.73	13.9
SVC 16	River	8.19	1 504	5.00	18.2
SVC 17	River	6.37	8 960	7.30	16.6
Losdoringspruit					
RQO		6.5 – 8.5	≤ 700	*	*
ESW 6	River	7.52	1 512	5.60	14.6
ESW 1	River	6.40	2 010	4.90	18.9
ESW 2	River/Wetland	7.81	1431	6.40	21.1

Levels exceeding recommended guideline levels are indicated in red, * No limit prescribed by relevant legislation

Water quality data for the Target Operations was considered from one main stem river in the Sandspruit River and one of its tributaries in the Losdoringspruit. According to the water quality of the Sandspruit River and its associated tributary, both systems indicated modified conditions. The Sandspruit River in the north of the project area is comprised of the main reach and one tributary which flows into the Sandspruit further downstream, below site SVC17, after flowing through the Target Operations. The Sandspruit, as represented by sites SVC 15, SVC 16 and SVC 17, was considered modified as measured parameters were outside TWQR and RQO limits for the reach. Site SVC 15 is upstream of the Target Operations which had elevated EC of 1482 µS/cm, above the RQO limit of ≤ 700 µS/cm, and an elevated pH of 8.61 above the TWQR and RQO limit of 8.5. SVC 16 is a midstream site which coincides with the centre of the Target Operations. It was found with an elevated EC of 1502 µS/cm. Site SVC 17 is a downstream site along the Sandspruit River which was found to have a pH below the TWQR and RQO limits of 6.5 and 6.37, respectively, as well as an elevated EC at 8960 µS/cm. The pH decreases in a downstream direction; while the EC increases. However, these changes are considered abrupt based on the proximity of the SVC 17 to the other sites and the operation. However, the source of modification at the site is unknown.

The Losdoringspruit contains site ESW 6 which is associated with the Freddies WRD; ESW 2 along a separate reach of the main tributary; and ESW 1 which is downstream site of the main tributary, as well as Site ESW 6 associated with the Freddies WRD. All of these points had elevated EC of 1 512 µS/cm above the RQO limit of ≤ 700 µS/cm. ESW 2 had an elevated EC concentration of 1431 µS/cm. The downstream site of ESW 1 was found to have elevated EC concentration of 1279 µS/cm. The DO at the site was below the TWQR of 5 mg/l at both sites, with concentrations of 4.90 and 2.1 due to the stagnant nature of the dam and wetland system. The pH at ESW 1 (6.40) is below the TWQR and RQO limit of 6.5.

Overall comments

The Sandspruit River reach associated with the Target Operations indicates elevated EC and pH upstream at site SVC 15 with an overall increase in EC and decrease in pH measured in a downstream direction to SVC 16 and SVC 17. The noted change between SVC15 and SVC 16 is however considered negligible with the spike in poor water quality measured at SVC 17 considered unrelated to the Target Operations (suspected to come from agricultural activity or Municipality sewage treatment plant (STP) as the associated Losdoringspruit has its confluence with the main stem river further downstream of SVC 17. The tributary however experiences modified water quality throughout as measured by EC and pH which is attributed to the mining activities associated with the Freddies 9 WRD remining activities. Water quality within all systems of the project area is considered to be a limiting factor for aquatic biodiversity due to elevated EC and diminished DO across the operation.

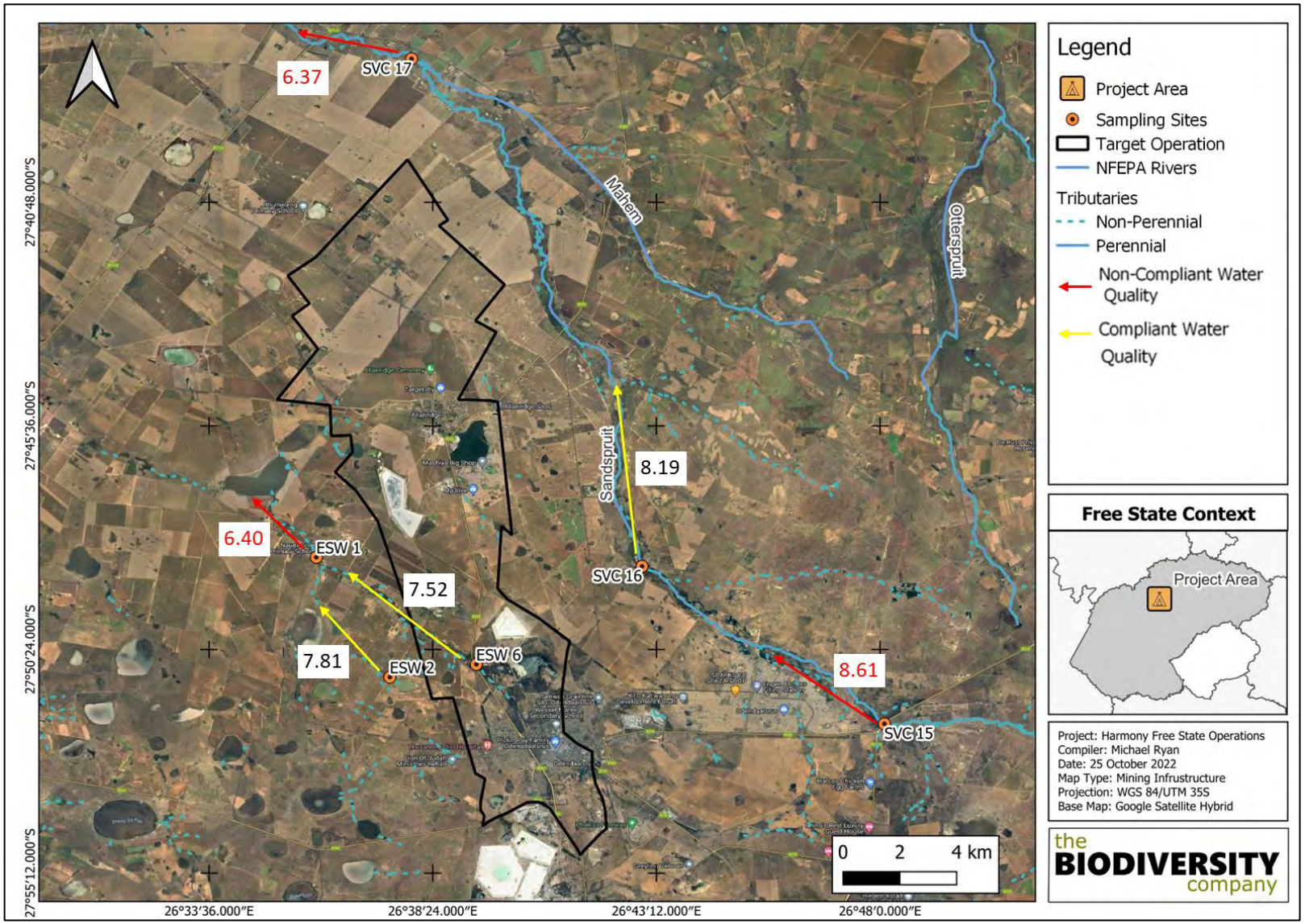


Figure 6-19: pH of each site associated with the Target Operations

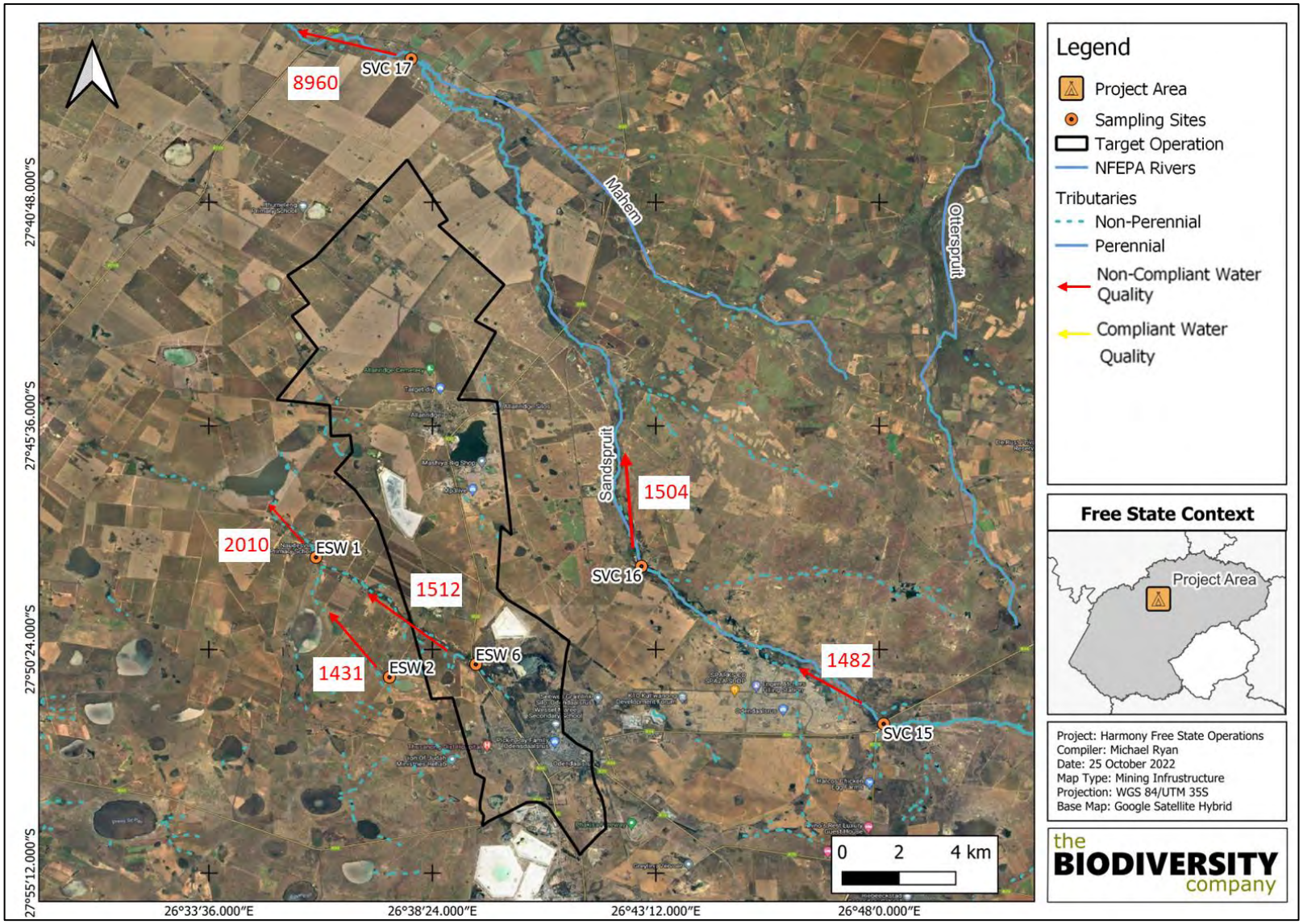


Figure 6-20: EC of each site associated with the Target Operations

6.2.2 Intermediate Habitat Integrity Assessment

The project area includes six SQR river reaches, which are the focus of the assessment. The eight SQRs were considered with some joint to form part of the same river. The reaches which pertain to the Harmony Free State Operations were assessed and were considered when completing the IHIA. The methodology was therefore applied with the results for the IHIA for the Sandspruit River, Mahem River, Rietspruit River, Sand River, Merriespruit River and Doring River presented in the Table 6-6, Table 6-7, Table 6-8, Table 6-9, Table 6-10 and Table 6-11, respectively.

Table 6-6: Results for the Sandspruit River habitat integrity assessment

Instream	Average Score	Impact Score
Water abstraction	12	6.72
Flow modification	16	8.32
Bed modification	13	6.76
Channel modification	16	8.32
Water quality	12	6.72
Inundation	17	6.8
Exotic macrophytes	7	2.52
Exotic fauna	8	2.56
Solid waste disposal	5	1.2
Total Instream		50.08
Category		D
Riparian	Average Score	Impact Score
Indigenous vegetation removal	8	4.16
Exotic vegetation encroachment	7	3.36
Bank erosion	6	3.36
Channel modification	15	7.2
Water abstraction	8	4.16
Inundation	16	7.04
Flow modification	12	5.76
Water quality	8	4.16
Total Riparian		60.8
Category		C

The Sandspruit River is a tributary of the Vaal River, with its confluence 50 km west of the project area. The results of the instream habitat assessment for the Sandspruit River indicated a class D or largely modified habitat conditions; while the riparian habitat assessment indicated a class C or moderately modified habitat conditions. This class indicates that a large loss of natural habitat, biota and basic ecosystem functions has occurred in the instream habitat; despite this, the basic ecosystem functions are still predominantly unchanged in the riparian habitat. The ecological condition of the watercourse was derived to be within the recommended management class C (moderately modified) of the RQOs for the catchment (Table 3-3) for riparian habitat but not for instream habitat. The surrounding land use of the river reach is presented in Figure 6-21. The identified dominant contributors to the modified state of the system are a result of multiple instream dams and weirs within the watercourse of the reach. Instream inundation was noted to be extensive, with the majority of the system forming wetland conditions as a result. This is a result of the weirs, dams and multiple road crossings which have poor

drainage capacity. This has resulted in instream channel, flow, and bed modification. Water quality modification results from surrounding agricultural influence, mining activities and surrounding settlements. WWTW are noted in the reach as another point source for discharge which results in water quality and flow modification. Water abstraction is noted for irrigation of the surrounding crops. It is therefore clear that modification to the Sandspruit River is from cumulative influences which cause compounding impacts that collectively contribute to the altered quality of habitat.

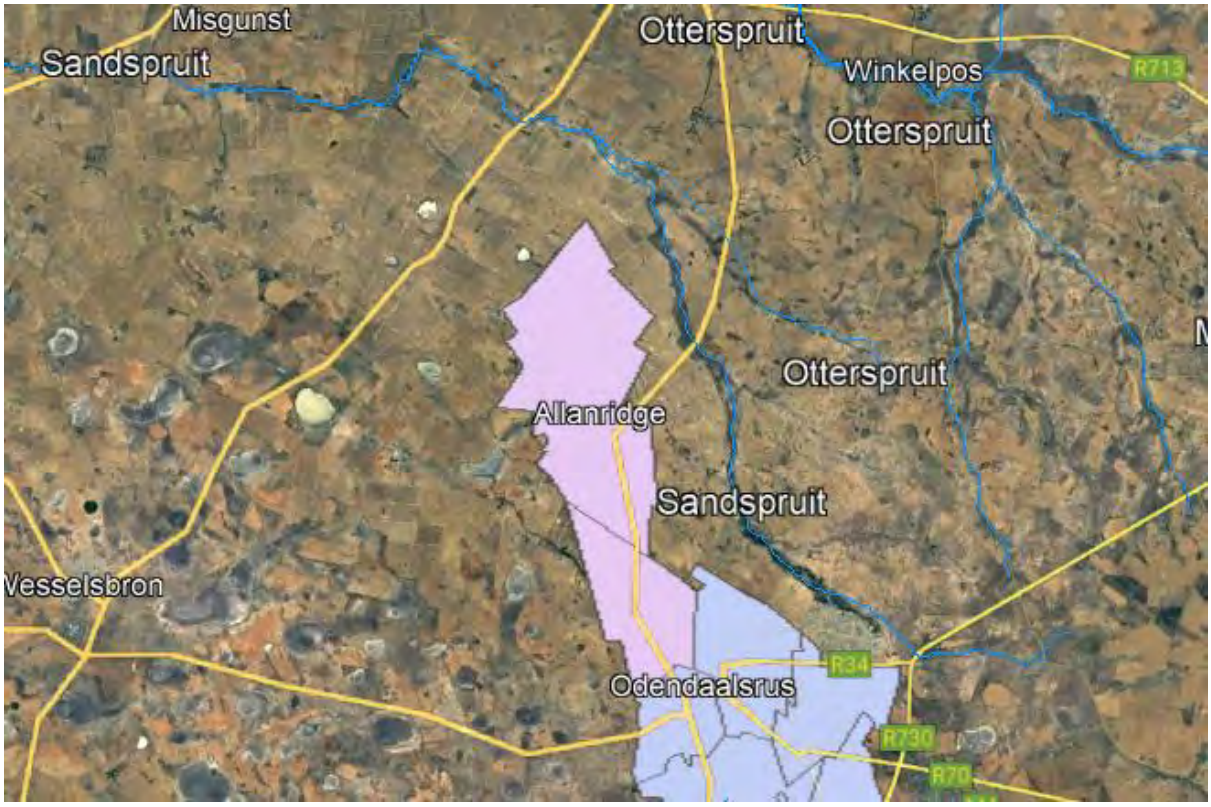


Figure 6-21: Aerial Imagery of the project area indicating land use along the Sandspruit River with the Target operation in Pink and Harmony One operation in purple (Google Earth 2022)

Table 6-7: Results for the Mahem River habitat integrity assessment

Instream	Average Score	Impact Score
Water abstraction	22	12.32
Flow modification	25	13
Bed modification	19	9.88
Channel modification	20	10.4
Water quality	18	10.08
Inundation	23	9.2
Exotic macrophytes	8	2.88
Exotic fauna	10	3.2
Solid waste disposal	7	1.68
Total Instream		27.36
Category		E
Riparian	Average Score	Impact Score
Indigenous vegetation removal	19	9.88

Instream	Average Score	Impact Score
Exotic vegetation encroachment	17	8.16
Bank erosion	12	6.72
Channel modification	20	9.6
Water abstraction	21	10.92
Inundation	21	9.24
Flow modification	18	8.64
Water quality	16	8.32
Total Riparian		28.52
Category		E

The Mahem River originates from the Rheeders Dam, located northwest of Welkom, and flows from the east to the west. The results of the instream and riparian habitat assessment in the Mahem River indicated class E or seriously modified habitat conditions in the watercourses and its tributaries. This class indicates that the loss of natural habitat, biota and basic ecosystem functions is extensive. The ecological condition of the watercourse was derived to be far outside of the recommended management class C (moderately modified) of the RQOs for the catchment (Table 3-3). The surrounding land uses of the river reach are presented in Figure 6-22. The identified dominant contributors to the modified state of the system are a result of surrounding land uses where a combination of damming of the system, abstraction and channel modification has resulted in the discontinuity of the system from its original confluence with the Vet River downstream. As a result, the system has extensive inundation with abstractions for surrounding agricultural and mining activities. Extensive water quality modification is noted in the reach with the measured water quality at the source of the reach in the PCDs considered to have pH and EC concentrations outside established TWQR and RQO limits. This is also observed in downstream sections of the reach which luminesce a green colour on imagery indicating excessive nutrients in the systems as well as the growth of indigenous and exotic macrophytes. Water abstraction is noted for irrigation of the surrounding crops. It is therefore clear that modification to the Mahem River is from cumulative influences which cause compounding impacts, that collectively contribute to the altered quality of habitat.



Figure 6-22: Aerial Imagery of the project area indicating land uses along the Sandspruit River with the Harmony One in purple and Saaiplaas Operation in blue, however there is overlap (Google Earth 2022)

Table 6-8: Results for the Rietspruit River habitat integrity assessment

Instream	Average Score	Impact Score
Water abstraction	11	6.16
Flow modification	14	7.28
Bed modification	7	3.64
Channel modification	11	5.72
Water quality	9	5.04
Inundation	15	6
Exotic macrophytes	5	1.8
Exotic fauna	6	1.92
Solid waste disposal	4	0.96
Total Instream		61.48
Category		C
Riparian	**Average Score**	**Impact Score**
Indigenous vegetation removal	13	6.76
Exotic vegetation encroachment	12	5.76
Bank erosion	9	5.04
Channel modification	16	7.68
Water abstraction	15	7.8
Inundation	11	4.84
Flow modification	13	6.24
Water quality	16	8.32
Total Riparian		47.56
Category		D

The Rietspruit originates within the vicinity of the Harmony One mining operations area and surface run-off generated from the north of the Rietspruit is directed from the north-east towards the south-west to the river. The Rietspruit has its confluence with the Sand River downstream of the Harmony Free State Operations. The results of the instream habitat assessment for the Rietspruit River indicated a class C or moderately modified habitat conditions; while the riparian habitat assessment indicated a class D or largely modified habitat conditions. This class indicates that a loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged in the instream habitat; while a large loss of natural habitat, biota and basic ecosystem functions has occurred in the riparian habitat. The ecological condition of the watercourse was derived to be within the recommended management class D (largely modified) of the RQOs for the catchment (Table 3-3). The surrounding land uses of the river reach are presented in Figure 6-23. The identified dominant contributors to the modified state of the system are a result of large dams upstream which result in flow modification and inundation. Channel modification results from multiple road crossings as well as encroachment from the upstream Henneman town and small holdings, as well as the downstream town of Virginia. These urban settlements combined with downstream mining activities and WWTW form the sources of water quality modification within the reach. It is therefore clear that modification to the Rietspruit River is from cumulative influences which cause compounding impacts, that collectively contribute to the altered quality of habitat.

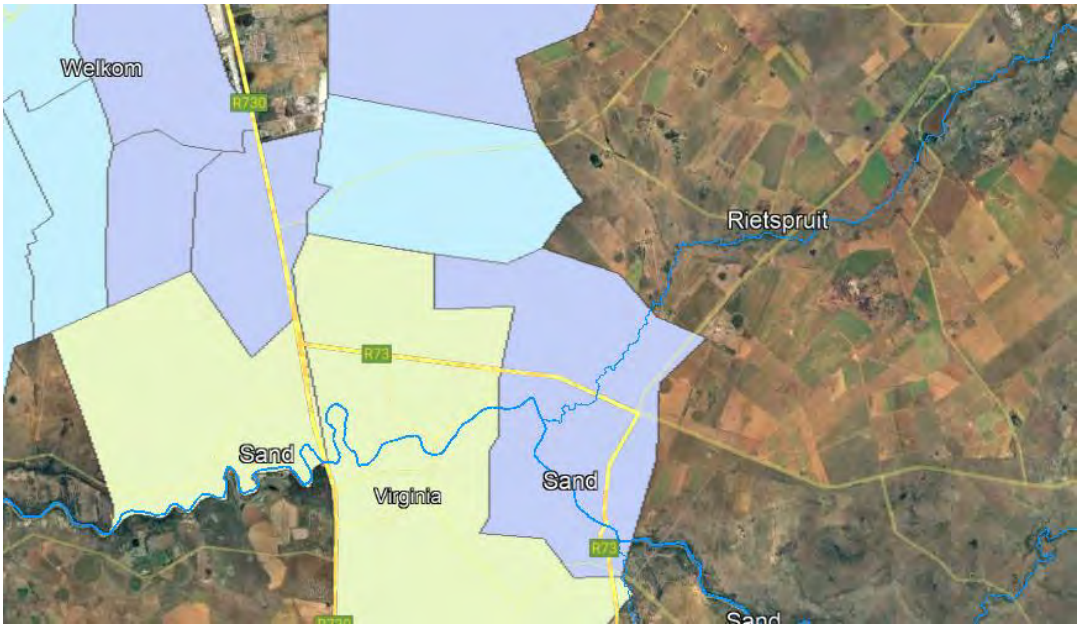


Figure 6-23: Aerial Imagery of the project area indicating land uses along the Sandspruit River with the Central operation in yellow, Harmony One in purple and Saaiplaas Operation in blue, however there is overlap (Google Earth 2022)

Table 6-9: Results for the Sand River habitat integrity assessment

Instream	Average Score	Impact Score
Water abstraction	15	8.4
Flow modification	13	6.76
Bed modification	14	7.28
Channel modification	14	7.28
Water quality	10	5.6
Inundation	9	3.6
Exotic macrophytes	6	2.16
Exotic fauna	8	2.56
Solid waste disposal	10	2.4
Total Instream		53.96
Category		D
Riparian	Average Score	Impact Score
Indigenous vegetation removal	19	9.88
Exotic vegetation encroachment	16	7.68
Bank erosion	13	7.28
Channel modification	17	8.16
Water abstraction	9	4.68
Inundation	11	4.84
Flow modification	15	7.2
Water quality	21	10.92
Total Riparian		39.36
Category		E

The Sand River is the largest drainage feature in the Harmony Free State mining operations area and originates approximately 120 km south-east from the mining operations in the Senekal District. Water in the Sand River flows into the Bloemhof Dam located approximately 120 km to the north-west of the operations. The results of the instream habitat assessment for the Sand River indicated a class D or largely modified habitat conditions; while the riparian habitat assessment indicated a class E or seriously modified habitat conditions. These classes indicate that a large loss of natural habitat, biota and basic ecosystem functions has occurred in the instream habitat; while the loss of natural habitat, biota and basic ecosystem functions in the riparian areas is extensive. The ecological condition of the watercourse was derived to be within the recommended management D (largely modified) of the RQOs for the catchment (Table 3-3) for the instream habitat but not for riparian habitat. The surrounding land uses of the river reach are presented in Figure 6-25. The riparian areas of the Sand River are heavily encroached on from urban settlements in the form of the town of Virginia and Harmony, industry, mining, and agriculture. These activities have resulted in indigenous vegetation removal for land use change with exotic vegetation encroachment occurring in disturbed and poorly rehabilitated areas – with multiple alien invasive species noted in the riparian areas. The encroachment and large-scale road crossings over the watercourse have resulted in channel modification, river migration has also been hindered through natural meandering and the formation of ox bow lakes. This was compound by instream weirs such as at site SVC 01 and poorly constructed dirt roads with no peers that have partly washed away but remain sources of inundation in the system. The surrounding land uses were identified as sources of water quality modification, with the tributaries that flow from mining activities etc. being found to have elevated pH and EC concentrations. It is however clear that modification to the Sand River is from cumulative influences which cause compounding impacts, that collectively contribute to the altered quality of habitat.

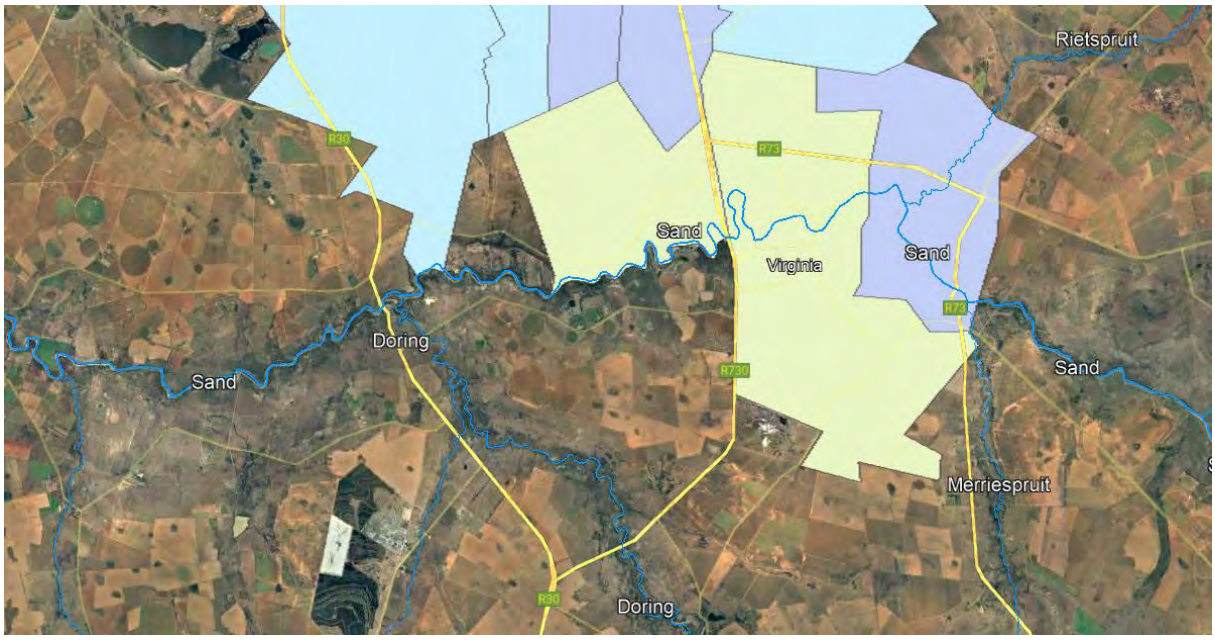


Figure 6-24: Aerial Imagery of the project area indication land use along the Sandspruit River with the Central operation in yellow, Harmony One in purple and Saaiplaas Operation in blue, however there is overlap (Google Earth 2022)

Table 6-10: Results for the Merriespruit River habitat integrity assessment

Instream	Average Score	Impact Score
Water abstraction	14	7.84
Flow modification	12	6.24
Bed modification	9	4.68
Channel modification	11	5.72

Instream	Average Score	Impact Score
Water quality	8	4.48
Inundation	13	5.2
Exotic macrophytes	6	2.16
Exotic fauna	4	1.28
Solid waste disposal	7	1.68
Total Instream		60.72
Category		C

Riparian	Average Score	Impact Score
Indigenous vegetation removal	11	5.72
Exotic vegetation encroachment	13	6.24
Bank erosion	8	4.48
Channel modification	7	3.36
Water abstraction	12	6.24
Inundation	7	3.08
Flow modification	9	4.32
Water quality	10	5.2
Total Riparian		61.36
Category		C

The results of the instream and riparian habitat assessment for the Merriespruit River indicated a class C or moderately modified habitat conditions. This class indicates that a loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged in the instream and riparian habitat. The ecological condition of the watercourse was derived to be within the recommended management C (moderately modified) of the RQOs for the catchment (Table 3-3). The surrounding land uses of the river reach are presented in Figure 6-25. The identified dominant contributors to the modified state of the system are a result of surrounding indigenous vegetation removal for the establishment of agriculture and of the urban areas in Virginia such as Mamelo and associated townships. The water requirements for these settlements and the agriculture have resulted in the establishment of multiple farm dams within the reach from which water may be abstracted. These dams, as well as encroachment and multiple road crossings has resulted in sections of the reach being inundated. These compounding impacts have resulted in the channel, bed, and flow modification of the reach. It is therefore clear that modification to the Merriespruit River is from cumulative influences which cause compounding impacts that collectively contribute to the altered quality of habitat.



Figure 6-25: Aerial Imagery of the project area indicating land uses along the Merriespruit River with the Central operation in yellow and Harmony One Operation in purple, however there is overlap (Google Earth 2022)

Table 6-11: Results for the Doring River habitat integrity assessment

Instream	Average Score	Impact Score
Water abstraction	10	5.6
Flow modification	19	9.88
Bed modification	16	8.32
Channel modification	15	7.8
Water quality	17	9.52
Inundation	10	4
Exotic macrophytes	6	2.16
Exotic fauna	5	1.6
Solid waste disposal	4	0.96
Total Instream		50.16
Category		D
Riparian	**Average Score**	**Impact Score**
Indigenous vegetation removal	16	8.32
Exotic vegetation encroachment	10	4.8
Bank erosion	15	8.4
Channel modification	17	8.16
Water abstraction	10	5.2
Inundation	11	4.84
Flow modification	15	7.2
Water quality	16	8.32
Total Riparian		44.76
Category		D

The Doring River originates from the south of the Joel Operations and water from this river flows into the Sand River located approximately 19 km to the northwest of the mining operations. The results of the instream and riparian habitat assessment for the Doring River indicated a category D or largely modified habitat conditions. This indicates that a large loss of natural habitat, biota and basic ecosystem functions has occurred in both the instream and riparian habitat. The ecological condition of the watercourse was derived to be within the recommended management C/D (moderately modified to largely modified) of the RQOs for the catchment (Table 3-3). The surrounding land uses of the river reach are presented in Figure 6-26. The identified dominant contributors to the modified state of the system are a result of the surrounding Joel and Beatrix mines, as well as some agricultural activities which have resulted in some water quality modification through slimes dams and nutrient runoff. The tributaries have some small dams with water abstraction used for irrigation. Channel modification is dominated by road crossings that hinder natural river migrations of meanders, as well as small scale encroachment by agriculture and mining. The river system has also experienced significant bank erosion which has resulted in bed modification as eroded material cause sedimentation of the systems, compounded by dryland agricultural activities. It is therefore clear that modification to the Doring River is from cumulative influences which cause compounding impacts that collectively contribute to the altered quality of habitat.

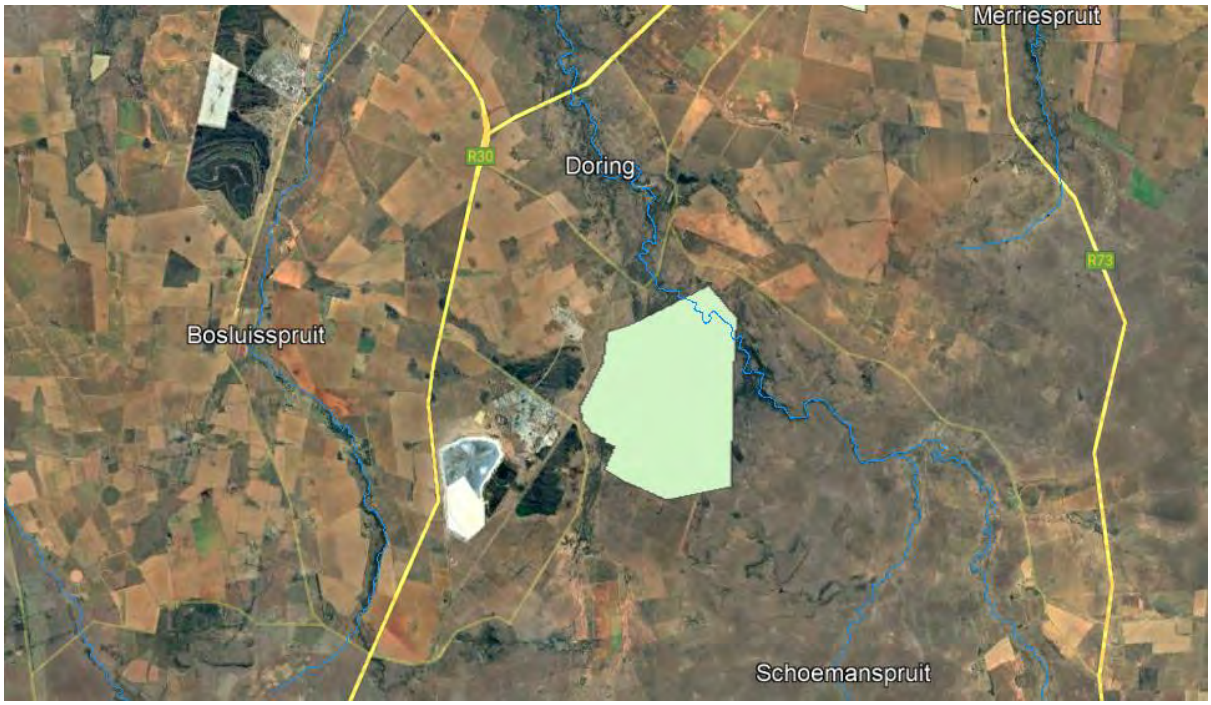


Figure 6-26: Aerial Imagery of the project area indicating land use along the Doring River with the Joel Operation in green (Google Earth 2022)

6.2.3 Aquatic Macroinvertebrates

6.2.3.1 Habitat Assessment System

A biotope rating of available habitat was conducted at each macroinvertebrate sampling site assessed to determine the diversity of habitat available for macroinvertebrate communities. The Rietspruit, Mahem, Sandspruit, Doring, Bosluisspruit, Theronspruit rivers and their tributaries were classed as lower foothills rivers (slope geoclass E); while the Sand River was classed as a lowland river (slope geoclass F). These river reaches were assigned different weightings (Table 6-12) for the various biotopes according to the importance value of their river zonation type (Rountree *et al*., 2000). The biotope categories were calculated according to the biotope rating assessment as applied in Tate and Husted (2015). A rating system of 0 to 5 was applied, 0 being not available and 5 being abundant and

diverse. The greater the biotope diversity present at a sampled site, the greater the habitat availability will be to sustain a richer aquatic macroinvertebrate community. The results of the biotope assessment for the May 2022 surveys are presented in Table 6-13 and Table 6-14.

Table 6-12: Biotope weightings for the watercourse geoclasses

Biotope	Lower Foothills	Lowland River
Stones in current (SIC)	18	15
Stones out of current (SOOC)	12	12
Bedrock	3	2
Aquatic vegetation	1	0.5
Marginal vegetation in current	2	2
Marginal vegetation out of current	2	2
Gravel	4	0.5
Sand	2	4
Mud	1	1.5

Table 6-13: Biotope diversity scores for the May 2022 assessment

Site	Rietspruit River		Sand River and tributaries					Mahem River
	SVC 03	New CP ESW	SVC 01	ESW 85	SVC 10/Mostert 12/ ESW 54	SVC 11	SVC 08	ESW 14
Geoclass	E				F			E
Stones in current	3	1	5	2	2	2	4	4
Stones out of current	2	1	3	3	1	4	3	0
Bedrock	5	4	0	0	2	2	2	0
Aquatic Vegetation	1	0	0	1	4	0	0	1
Marginal Vegetation In Current	3	3	2	3	3	0	2	0
Marginal Vegetation Out Of Current	1	2	1	2	3	2	1	3
Gravel	4	0.5	3	3	2	4	4	0
Sand	3	1	1	2	4	3	4	0
Mud	3	0	0	2	4	2	2	3
Total Score (X / 45)	25	12.5	15	18	25	19	22	11
Weighted Biotope Score (%)	56	25	54	40	37	46	56	36
Biotope Category (Tate and Husted, 2015)	C	F	C	E	E	D	C	E

Table 6-14: Biotope diversity scores for the May 2022 assessment continued

Site	Sandspruit River			Doring River				Bosluisspruit River	Theronspruit River	Losdoringspruit	
	SVC 15	SVC 16	SVC 17	ESW 82	SVC 04	SVC 05	SVC 7	SVC 6	ESW 80	ESW 1	ESW 2
Geoclass	E			E				E	-	-	-
Stones in current	0	1.5	1	4	3	3	2.5	0	3	0	0

Site	Sandspruit River			Doring River				Bosluisspruit River	Theronspruit River	Losdoringspruit	
	SVC 15	SVC 16	SVC 17	ESW 82	SVC 04	SVC 05	SVC 7	SVC 6	ESW 80	ESW 1	ESW 2
Stones out of current	1	0	0	3	2	2	0	1	1	1	0
Bedrock	0	1	0	1	1	0	2	1	0	0	0
Aquatic Vegetation	0.5	4	3	2	0	1	2	3	0	4	3
Marginal Vegetation In Current	0	3	4	4	2	2	3	1	3	4	0
Marginal Vegetation Out Of Current	3	4	3	3	2	3	0	3	1	3	3
Gravel	0	3	1	5	4	2	3	0	4	1	0
Sand	1	3	1	4	4	3	3	1	4	1	0
Mud	3	4	4	2	2	1	4	3	3	4	2
Total Score (X / 45)	8.5	23.5	17	28	20	17	19.5	13	19	18	8
Weighted Biotope Score (%)	10	31	20	70	51	46	36	14	45	18	5
Biotope Category (Tate and Husted, 2015)	F	E	E	B	C	D	E	F	D	F	F

The sampled river reaches generally presented a low to moderate diversity of biotopes and hydraulic habitat variations. Therefore, a moderate macroinvertebrate community diversity would be expected in the sampled systems, namely the Mahem, Sandspruit, Bosluisspruit, and Theronspruit rivers and their tributaries. This included some sites on the Rietspruit, Sand and Doring rivers.

A small portion of sampled sites on the Rietspruit (SVC 3), Sand (SVC 01, SVC 11 and SVC 08) and Doring (ESW 82, SVC 04) rivers presented a higher diversity of biotopes and hydraulic habitat variations, capable of supporting diverse macroinvertebrate communities.

6.2.3.2 South African Scoring System

The aquatic macroinvertebrate SASS5 results and associated ecological categories for the March 2022 surveys are presented in the respective mine sections to follow:

6.2.3.2.1 Central Operations

During the surveys, the SASS5 scores recorded for the Central Operations ranged from 31 at SVC 10 (Sand River Tributary) to 104 at SVC 01 (Sand River) (Table 6-15). The number of taxa indicated that the sampled systems had a low diversity of aquatic macroinvertebrates ranging from 9 at SVC 10 to 23 at SVC 05 (Doring River). The Average Scores Per Taxa (ASPT- average sensitivity scores) indicated that the sampled river reaches comprised primarily of pollution tolerant macroinvertebrate taxa (Intolerance Rating < 5) ranging from 3.4 at SVC 10 to 5.5 at SVC 01. The low diversity of semi-intolerant taxa (Intolerance Rating 5 - 10) sampled and the absence of intolerant taxa (Intolerance Rating 11 - 15) across the project area indicated compromised macroinvertebrate communities across the sampled systems at the time of the survey. According to biological banding for the Highveld – Lower ecoregion, the biotic integrity of the sampled sites was categorised and ranged from Largely Natural (category B) to Seriously Modified (category E/F). This indicates that the macroinvertebrate assemblages have been impacted to varying degrees across the systems with water quality (dissolved solid concentrations and low dissolved oxygen levels) and poor habitat/ habitat disturbances influencing the community structures. It should be noted that the macroinvertebrate community (based on ASPT scores) in the Sand River deteriorated in downstream direction which coincides with the location of sites, upstream

(SVC 01), midstream (SVC 11) and downstream (SVC 08) of the anthropogenic catchment impacts of Virginia and those along the Doring River which drains into the Sand River above SVC 08.

Table 6-15: Macroinvertebrate assessment results recorded for the Central Operations

Site	SASS5 Score	No. of Taxa	ASPT*	Category	Comment
Rietspruit River					
SVC 03	70	17	4.1	C	Adequate water quality. Moderate habitat (56%)
New CP ESW	85	19	4.5	B	Adequate water quality. Poor habitat (25%)
Sand River					
SVC 01	104	19	5.5	B	Low Dissolved Oxygen. Moderate habitat (54%)
SVC 10/Mostert 12/ ESW 54	31	9	3.4	E/F	High salts & low Dissolved Oxygen. Poor habitat (37%)
SVC 11	54	14	3.9	D	Low Dissolved Oxygen. Moderate habitat (46%)
SVC 08	72	17	4.2	C	Adequate water quality. Moderate habitat (56%)
Doring River					
SVC 05	100	23	4.3	B	Adequate water quality. Moderate habitat (46%)
SVC 07	72	16	4.5	C	High salts. Poor habitat (36%)
Bosluisspruit River					
SVC 06	51	13	3.9	E/F	High salts. Poor habitat (14%)

6.2.3.2.2 Harmony One Operations

As per the Central Operations, the Harmony One Operations sites were predominantly the same sites with some site not shared between the two operations. Therefore, the SASS5 results are largely similar.

The SASS5 scores recorded for the Harmony One Operations ranged from 31 at SVC 10 (Sand River Tributary) to 104 at SVC 01 (Sand River) (Table 6-16). The number of taxa indicated that the sampled systems had a low diversity of aquatic macroinvertebrates ranging from 9 at SVC 10 to 25 at SVC 15 (Sandspruit River). The average sensitivity scores indicated that the sampled river reaches comprised primarily of pollution tolerant macroinvertebrate taxa ranging from 3.4 at SVC 10 to 5.5 at SVC 01. The biotic integrity of the sampled sites was categorised and ranged from Largely Natural (category B) to Seriously Modified (category E/F). This indicates that the macroinvertebrate assemblages have been impacted to varying degrees across the systems with water quality (dissolved solid concentrations and low dissolved oxygen levels) and poor habitat/ habitat disturbances influencing the community structures.

Table 6-16: Macroinvertebrate assessment results recorded for the Harmony One Operations

Site	SASS5 Score	No. of Taxa	ASPT*	Category	Comment
Rietspruit River					
SVC 03	70	17	4.1	C	Adequate water quality. Moderate habitat (56%)
New CP ESW	85	19	4.5	B	Adequate water quality. Poor habitat (25%)
Sand River					
SVC 01	104	19	5.5	B	Low Dissolved Oxygen. Moderate habitat (54%)
ESW 85	47	13	3.6	E/F	Moderate salts & low Dissolved Oxygen. Poor habitat (40%)
SVC 10/Mostert 12/ ESW 54	31	9	3.4	E/F	High salts & low Dissolved Oxygen.

Site	SASS5 Score	No. of Taxa	ASPT*	Category	Comment
					Poor habitat (37%)
SVC 08	72	17	4.2	C	Adequate water quality. Moderate habitat (56%)
Mahem River					
ESW 14	39	11	3.5	E/F	High salts & low Dissolved Oxygen. Poor habitat (37%)
Sandspruit River					
SVC 15	99	22	4.5	B	Adequate water quality. Poor habitat (10%)
SVC 16	111	25	4.4	B	Adequate water quality. Poor habitat (31%)

6.2.3.2.3 Joel Operations

The SASS5 scores recorded for the Joel Operations ranged from 62 at ESW 80 (Theronspruit River) to 188 at ESW 82 (Doring River) (*Table 6-17*). The number of sampled taxa indicated that the Doring system had a moderate diversity of aquatic macroinvertebrates ranging from 23 at SVC 04 and SVC 05 to 35 at ESW 82. The Theronspruit had a lower and depauperate diversity at 13 taxa. The average sensitivity scores indicated that the sampled river reaches comprised primarily of pollution tolerant macroinvertebrate taxa ranging from 4.3 at SVC 05 to 5.4 at ESW 82, with a low diversity of semi-intolerant taxa resulting in slightly higher ASPT values compared to the larger project area. The biotic integrity of the sampled sites ranged from Natural (category A) to Moderately Modified (category C). This indicates that the macroinvertebrate assemblages are in a stable condition. Despite the stable conditions, these two systems have water quality (dissolved solid concentrations) and moderate habitat/ habitat disturbances influencing the community structures. It should be noted that the macroinvertebrate community (based on ASPT scores) in the Doring River deteriorated in downstream direction which coincides with the location of sites, upstream (ESW 82), midstream (SVC 04) and downstream (SVC 05) of the anthropogenic catchment impacts which includes mining present in the reach from both the Beatrix and Joel Operations.

Table 6-17: Macroinvertebrate assessment results recorded for the Joel Operations

Site	SASS5 Score	No. of Taxa	ASPT*	Category	Comment
Doring River					
ESW 82	188	35	5.4	A	Adequate water quality. Diverse habitat (70%)
SVC 04	107	23	4.7	B	High salts. Moderate habitat (51%)
SVC 05	100	23	4.3	B	High salts. Moderate habitat (46%)
Theronspruit River					
ESW 80	62	13	4.8	C	High salts & slightly low dissolved oxygen. Moderate habitat (45%)

6.2.3.2.4 Saaiplaas Operations

The SASS5 scores recorded for the Saaiplaas Operations ranged from 54 at SVC 11 (Sand River) to 72 at SVC 08 (Sand River) and SVC 07 (Doring River) (Table 6-18). The number of taxa indicated that the sampled systems had a low diversity of aquatic macroinvertebrates ranging from 14 at SVC 11 (Sand River) to 17 at SVC 03 and SVC 03 (Rietspruit and Sand River, respectively). The average sensitivity scores indicated that the sampled river reaches comprised primarily of pollution tolerant macroinvertebrate taxa ranging from 3.9 at SVC 11 to 4.5 at SVC 07. The biotic integrity of the sampled sites ranged from Moderately Modified (category C) to Largely Modified (category D). This indicates

that the macroinvertebrate assemblages have been impacted to varying degrees across the systems with water quality (dissolved solid concentrations and low dissolved oxygen levels) and moderate habitat/ habitat disturbances influencing the community structures.

Table 6-18: Macroinvertebrate assessment results recorded for the Saaiplaas Operations

Site	SASS5 Score	No. of Taxa	ASPT*	Category	Comment
Rietspruit River					
SVC 03	70	17	4.1	C	Adequate water quality. Moderate habitat (56%)
Sand River					
SVC 11	54	14	3.9	D	Low Dissolved Oxygen. Moderate habitat (46%)
SVC 08	72	17	4.2	C	Adequate water quality. Moderate habitat (56%)
Doring River					
SVC 07	72	16	4.5	C	High salts. Poor habitat (36%)

6.2.3.2.5 Target Operations

The Target Operations SASS5 scores ranged from 74 at ESW 1 (Sandspruit Tributary) to 111 at SVC 16 (Sandspruit River) (*Table 6-19*). The sampled systems had a low to moderate diversity of aquatic macroinvertebrates ranging from 18 at ESW 1 and ESW 2 (Sandspruit Tributary) to 25 at SVC 16 (Sandspruit). The sampled river reaches comprised primarily of pollution tolerant macroinvertebrate taxa with average sensitivity scores ranging from 3.8 at SVC 17 to 4.7 at ESW 2. The biotic integrity of the sampled sites ranged from Largely Natural (category B) to Moderately Modified (category C). This indicates that the macroinvertebrate assemblages are in a stable condition. Despite the stable conditions, these two systems have water quality (dissolved solid concentrations) and poor habitat/ habitat disturbances influencing the community structures. It should be noted that the macroinvertebrate community (based on ASPT scores) in the Sandspruit River deteriorated in downstream direction which coincides with the location of sites, upstream (SVC 15), midstream (SVC 16) and downstream (SVC 17) of the anthropogenic catchment impacts associated with Odendaalrus and Allanridge. These impacts include untreated effluent from the Odendaalrus municipality STP and runoff from agricultural activities and mining activity influence.

Table 6-19: Macroinvertebrate assessment results recorded for the Target Operations

Site	SASS5 Score	No. of Taxa	ASPT*	Category	Comment
Sandspruit River					
SVC 15	99	22	4.5	B	Adequate water quality. Poor habitat (10%)
SVC 16	111	25	4.4	B	Adequate water quality. Poor habitat (31%)
SVC 17	75	20	3.8	C	High salts. Poor habitat (20%)
Losdoringspruit					
ESW 1	74	18	4.1	C	Moderate salts. Poor habitat (18%)
ESW 2	84	18	4.7	B	Adequate water quality. Poor habitat (5%)

6.2.3.3 Macroinvertebrate Response Assessment Index

The Macroinvertebrate Response Assessment Index (MIRAI) methodology was conducted according to Thirion (2007). Data collected from the SASS5 method was applied to the MIRAI model. The MIRAI model provides a habitat-based cause-and-effect foundation to interpret the deviation of the aquatic invertebrate community (assemblage) from the reference condition (unmodified river). A low impact score indicates a large portion of the macroinvertebrate community is missing due to altered riverine conditions (ecological drivers – flow, habitat and water quality). A high impact score indicates the macroinvertebrate community is largely intact as a result of an unmodified driver(s). It is important to note that rivers with a single biological sampling site (Mahem, Bosluisspruit & Theronspruit) are not ideal systems for MIRAI models due to the limited data available for calculations, or were wetland dominated systems (Sandspruit Tributary). Therefore, these systems were excluded from MIRAI analyses. It is recommended that additional biological sampling sites be included for the monitoring programme to assess the MIRAI for these systems (where appropriate).

The MIRAI results for the Rietspruit (sites SVC 03, New CP ESW) derived an ecological category of largely modified (category D), which met the Target Ecological Category (TEC) for the catchment. The main driver contributing to the modified state was water quality modification within the reach. Additionally, flow modification, and to a lesser degree habitat alterations were deemed contributing factors to the altered macroinvertebrate communities. The absence of tolerant and water quality sensitive taxa such as Heptageniidae (Flatheaded mayflies) and Leptophlebiidae (Prongill mayflies), among other common missing taxa, confirms the modified water quality in the Rietspruit. The sensitive taxa collected included Atyidae (Freshwater Shrimp – sensitivity score 8), Baetidae 2 sp (Mayflies - 6) and Hydropsychidae 2 sp (Caddisflies - 6). It can be derived from the results that the level of water quality modification, instream habitat modification and altered flow may stem from agriculture and mining (contaminated return flows); as well as catchment and channel alteration for land use which includes impoundments, livestock pressure on riverine habitat and resultant erosion. The cumulative impacts within the catchment were observed by excessive algal growth (SVC 03) and sedimentation in the reach highlighting the need for responsible management of the Rietspruit catchment.

The MIRAI results for the Sand River (sites SVC 01, SVC 11 & SVC 08) derived an ecological category of largely modified (category D) which met the TEC for the catchment. The main drivers contributing to the modified state were flow and water quality modification within the reach. Additionally, habitat alterations were deemed as contributing factors to altered macroinvertebrate communities. The absence of tolerant and water quality sensitive taxa such as Heptageniidae (Flatheaded mayflies) and Leptophlebiidae (Prongill mayflies), among other common missing taxa, confirms the modified water quality in the Sand River. The sensitive taxa collected included Atyidae (Freshwater Shrimp – sensitivity score 8), Baetidae >2 sp (Mayflies - 12), Tricorythidae (Stout Crawlers - 9) and Hydropsychidae >2 sp (Caddisflies - 12), notably in the upper reaches and not at the midstream and downstream site. The results indicate that this downstream deterioration can be attributed to contaminated water from the midstream tributary systems (ESW 85 and SVC 10/Mostert 12/ ESW 54 in Table 6-16) and downstream tributaries (Doring and associated Bosluisspruit and Theronspruit sites in Table 6-15 and Table 6-17). The Sand River ecological drivers have cumulatively been subjected to catchment and channel alteration for land use which includes impoundments and sand mining, livestock, agriculture and mining (contaminated return flows). To avoid further deterioration responsible management of the catchment and watercourse habitat of this river and its tributaries is required.

The MIRAI results for the Doring River (sites ESW 82, SVC 04, SVC 05 & SVC 07) derived an ecological category of largely modified (category D) which fell slightly short of the TEC for the catchment. All three drivers were largely modified contributing to the modified macroinvertebrate communities. The absence of tolerant and water quality sensitive taxa such as Aeshnidae (Hawkers & Emperor Dragonflies) and Leptophlebiidae, among other common missing taxa, confirms the modified water quality in the Doring River. The sensitive taxa collected included Atyidae (Freshwater Shrimp – sensitivity score 8), Baetidae >2 sp (Mayflies - 12), Corduliidae/ Macromiidae (Cruiser Dragonflies) and Hydropsychidae 2 sp

(Caddisflies - 6), notably in the upper reaches (ESW 82) and not at the midstream and downstream sites. The results indicate that this downstream deterioration can be attributed to contaminated water from the midstream tributary system (Theronspruit in Table 6-17) and downstream tributaries (Bosluisspruit in Table 6-15). The Doring River ecological drivers have cumulatively been subjected to catchment and channel alteration for land use similar to the Sand River, with mining in the upper reaches and along the tributaries. To avoid further deterioration responsible management of the catchment and watercourse habitat of this river and its tributaries is required.

The MIRAI results for the Sandspruit (sites SVC 15, SVC 16 & SVC 17) derived an ecological category of largely modified (category D), which fell short of the MIRAI RQO of category C for the catchment. The main drivers contributing to the modified state were flow and water quality modification within the reach. Additionally, habitat alterations were deemed contributing factors to altered macroinvertebrate communities with excessive algal growth observed at SVC 15 and SVC 17. The absence of tolerant and water quality sensitive taxa such as Caenidae (Squaregills/Cainfly mayflies), Leptophlebiidae, Aeshnidae and Gomphidae (Clubtail dragonflies), among other common missing taxa, confirms the modified water quality in the Sandspruit. The sensitive taxa collected included Baetidae 2 sp (Mayflies - 6), Hydrometridae (Water measurers - 8) and Dixidae (Dixid midges 10). The results indicate that this modified community can be attributed to contaminated water from input from extensive agriculture, WWTWs and other channel alterations (Table 6-19) and requires management.

Table 6-20: MIRAI Score for the sampled systems (Main stems)

Invertebrate Metric Group	Rietspruit	Sand	Doring	Sandspruit
Sites	SVC 03 New CP ESW	SVC 01 SVC 11 SVC 08	ESW 82 SVC 04 SVC 05 SVC 07	SVC 15 SVC 16 SVC 17
Flow Modifications	38.1	36.9	50.6	36.9
Habitat	53.3	61.3	56.3	58.1
Water Quality	37.8	43.5	53.8	39.6
Ecological Score	43.3	47.6	53.7	45.2
Category	D	D	D	D
MIRAI RQO	-		-	**C (≥ 62)**
TEC RQO	D		C/D	C

6.2.4 Fish Community Assessment

The expected fish community and sensitivity ratings to no-flow and physicochemical modifications are presented in Table 6-21. According to the expected species list, nine (9) indigenous fish are expected within the project area. The presence/absence of fish species collected during the low flow assessment are presented in Table 6-22 and Table 6-23 for the various reaches.

A single species was collected from the Rietspruit reach, *Pseudocrenilabrus philander*. Moderate cover features were sampled and an increase in the diversity of species was expected within the reach. No fish were collected in the downstream site New CP ESW. Migration barriers below the downstream site contribute to the movement of fish within the reach. Additionally, extremely low flows during the dry season reduced suitable habitat for sensitive species to flow modification.

A total of five indigenous species were collected in the Sand River reach, including a single exotic species, *Gambusia affinis*, which was further collected throughout the project area. Two cyprinid species were collected, including *Labeo umbratus* and *Labeobarbus aeneus*. Of note was that no *Enteromius* species were collected within the reach. Despite predominantly sandy substrate throughout the reach, adequate cover features for a more diverse fish community were present and indicated flow and water quality modifications contributing to a reduced biological integrity.

A single fish species was collected at site ESW14 on the Mahem River, *Tilapia sparrmanii*. Habitat diversity was limited to sand and mud substrate and aquatic and marginal vegetation. A low diversity of fish was expected at the site; however, the presence of additional hardy species was expected, including *Clarias gariepinus*.

Three species were collected in the Sandspruit River, including *Enteromius paludinosus*. The fish community comprised of largely tolerant species and flow sensitive species were absent. Additionally, water quality perturbations in the upper reaches as observed by eutrophication contributed to adverse conditions to local fish species.

Cover features sampled within the Doring River were limited and would contribute to the absence of several species as only three indigenous species were collected that have high preference for standing waters. The presence of instream impoundments within the Bosluisspruit would limit migration and the presence of several species in the upper reaches and no indigenous species were collected within the reach. A single exotic species was collected, *G. affinis* at site SVC 6.

No fish were collected within the Theronspruit. Low flows and poor water quality contribute to adverse conditions to aquatic biota. No fish were collected at sites ESW 1 and ESW 2 within unnamed tributaries of the Gelukspan. A low diversity of fish would be expected within the reach as the systems are cut off from larger river systems. Expected species within the reach would be limited to *Clarias gariepinus* and *Tilapia sparrmanii*.

The results of the Fish Response Assessment Index (FRAI) are presented in Table 6-22 and Table 6-23. Results indicate the fish community within the Rietspruit River was classed as seriously modified (Category E) which is attributed to the presence of 11% of the expected fish community.

The FRAI scored of the Sand River was calculated at 37%, rating the fish community as seriously modified (Class E). Most expected fish species within the reach were absent, with a low frequency of occurrence of collected species in the reach, and only 5 of the 9 species collected. The low frequency of collected species reduced the ecological integrity if the fish community.

A single species was collected in the Mahem reach, representing 20% of the expected species and an ecological category of Category D/E. Within the Sandspruit reach, 60% of the expected fish community was collected at site SVC16. The frequency of *C. gariepinus* and *E. paludinosus* within the reach improved the ecological integrity, and the reach was rated as largely modified (Category D).

The Doring were classed as seriously modified. The diversity of hydraulic biotopes and cover features were limited within the system and were a limiting factor to the fish community, however, only 3 species were collected in the reach with a low frequency of occurrence. Water quality perturbations within the Doring further reduced the biotic integrity.

No indigenous fish species were collected within the Bosluisspruit, Theronspruit and the sites on the unnamed tributary (sites ESW 1 and ESW 2). These sites were rated as seriously modified (Category E), and the absence of fish was attributed to various site-specific modifications (i.e. poor cover features) and catchment level impacts, including numerous impoundments restricting migration. Illustrations of fish collected during the study are presented in Table 6-24.

Table 6-21: Summary of the fish species sensitivity for the expected fish species list

Scientific name	Sensitivity	
	No-flow	Phys-chem
Austroglanis sclateri	2.9	
Clarias gariepinus	1.7	1.0
Enteromius anoplus	2.3	2.6
Enteromius paludinosus	2.3	1.8
Labeo capensis	3.1	3.1

Labeo umbratus	2.7	1.6
Labeobarbus aeneus	3.3	2.5
Pseudocrenilabrus philander	1.0	1.4
Tilapia sparrmanii	0.9	1.4
Average Sensitivity	2.1	2.0

Table 6-22: Presence/absence, of fish species for the sampled sites and FRAI results per reach

Site	Rietspruit River		Sand River					Mahem River	Sandspruit River		
	SVC 3	New CP ESW	SVC 01	ESW 85	SVC 10/Mostert 12/ ESW 54	SVC 11	SVC 08	ESW 14	SVC 15	SVC 16	SVC 17
Austroglanis sclateri	-	-	-	-	-	-	-	-	-	-	-
Clarias gariepinus	-	-	1	-	-	-	1	-	1	1	-
Enteromius anoplus	-	-	-	-	-	-	-	-	-	-	-
Enteromius paludinosus	-	-	-	-	-	-	-	-	1	1	1
Gambusia affinis	-	-	1	1	-	1	1	-	-	-	-
Labeo capensis	-	-	-	-	-	-	-	-	-	-	-
Labeo umbratus	-	-	1	-	-	-	-	-	-	-	-
Labeobarbus aeneus	-	-	-	-	-	-	1	-	-	-	-
Pseudocrenilabrus philander	1	-	-	-	1	-	-	-	-	1	-
Tilapia sparrmanii		-	-	1	-	-	-	1	-	-	-
Total	1	0	3	2	1	1	1	1	2	3	1
Expected	9	9	9	5	5	9	9	5	5	5	7
% Community Collected	11	0	33	40	20	11	11	20	40	60	14
FRAI Score and Category	25.1% Category E		37% Category E					38.3% Category D/E	43% Category D		

Species in red indicate alien invasives

Table 6-23: Presence/absence of fish species for the sampled sites and FRAI results per reach

Site	Doring River				Bosluisspruit River	Theronspruit River	Losdoringspruit	
	ESW 82	SVC 04	SVC 05	SVC 7	SVC 6	ESW 80	ESW 1	ESW 2
Austroglanis sclateri	-	-	-	-	-	-	-	-
Clarias gariepinus	-	-	-	1	-	-	-	-
Enteromius anoplus	-	-	-	-	-	-	-	-
Enteromius paludinosus	-	-	-	-	-	-	-	-
Gambusia affinis	-	-	-	1	1	-	-	-
Labeo capensis	-	-	-	-	-	-	-	-
Labeo umbratus	-	-	-	-	-	-	-	-
Labeobarbus aeneus	-	-	-	-	-	-	-	-
Pseudocrenilabrus philander	-	-	1	-	-	-	-	-
Tilapia sparrmanii	1	-	1	-	-	-	-	-
Total	1	0	2	2	1	0	0	0
Expected	7	9	9	9	6	4	3	3
% Community Collected	14	0	22	22		0	0	0
FRAI Score and Category	31% Category E				20% Category E	20% Category E	20% Category E	

Species in red indicate alien invasives

Table 6-24: Fish species sampled in the project area with associated pictures (May 2022)

Clarias gariepinus

Enteromius paludinosus

Labeo umbratus

Labeobarbus aeneus

Pseudocrenilabrus philander

Tilapia sparrmanii


Gambusia affinis (Exotic)



Species in red indicate alien invasives

6.2.5 Present Ecological State

The PES was only applied to the four river systems on which both the MIRAI and FRAI were applied to that include the Rietspruit, Sandspruit, Doring and Sand rivers. The Rietspruit River experienced modified water quality with largely modified riparian areas. This resulted in largely modified macroinvertebrate communities and seriously modified fish communities. The Sand River experienced modified water quality at the end of the reach with seriously modified riparian areas due to the surrounding landuses. This resulted in largely modified macroinvertebrate communities and seriously modified fish communities. The Sandspruit River experienced modified water quality with moderately modified riparian areas. This resulted in largely modified macroinvertebrate communities and seriously modified fish communities. The Doring River experienced modified water quality with largely modified riparian areas. This resulted in largely modified macroinvertebrate communities and modified fish communities. The results of the Ecostatus determination indicates that the Rietspruit River and Sand River were in a largely to seriously modified state during the 2022 study (Table 6-25) The Sandspruit River and Doring River were determined to have a largely modified Ecostatus. This indicates that the river systems associated with the Harmony Free State Operations have experienced modification with a key factor resulting in compounding impacts the degradation of water quality in the systems.

Table 6-25: The Present Ecological Status of the rivers pertaining to the Harmony Free State Operations

Category	Score	Ecological Category	Score	Ecological Category	Score	Ecological Category	Score	Ecological Category
	Rietspruit River		Sand River		Sandspruit River		Doring River	
Riparian	47.56	D.	39.36	E	60.8	C	44.76	D
Macroinvertebrate	43.3	D	47.6	D	53.7	D	45.2	D
Fish Assemblage	25	E	37	E	43	E	31	E
Ecostatus	41.66		41.40		55.00		42.09	
	Largely to Seriously Modified (category D/E)		Largely to Seriously Modified (category D/E)		Largely Modified (category D)		Largely Modified (category D)	

7 Monitoring programme

Based on the results of the aquatic biomonitoring study (May 2022), the RQO's for the applicable catchments, the following monitoring checklist was established (Table 7-1). The prescribed biomonitoring targets was a combination of both RQOs, TWQ for aquatic biota and May 2022 biomonitoring results. An analysis of sampling sites distribution, habitat availability on site, flow as well as received data was used to refine the number of sampling sites as well as which methodologies to apply at each site which is presented in Table 7-2. The monitoring program will be reviewed every two years by Harmony to assess its applicability based on mining activity still occurring. This biomonitoring plan applies was compiled according to different river systems:

Central Operation – Rietspruit River, Merriespruit River, Doring River, Sand River and Bosluisspruit River

Harmony One Operations – Rietspruit River, Mahem River, Sand River and Sandspruit River

Joel Operations – Doring River and Theronspruit River

Saaiplaas Operations – Rietspruit River, Mahem River, Sand River and – Doring River

Target Operations – Sandspruit River and Losdoringspruit

Based on the outcomes of this study, further actions are recommended:

- The biomonitoring programme is imperative to establish biological trends and monitor the impacts of the mine throughout the lifecycle of the mine which includes post closure monitoring;
- Auditing of the recommended mitigation actions for the project infrastructure must be conducted every two years;
- The results of the established surface water monitoring programme should be integrated into the biomonitoring programme to provide insight;
- Due to the inefficacy of fish sampling in the systems, diatoms were suggested as a better ecological indicator in many systems;
- Alien invasive vegetation assessments must be conducted in accordance with the terrestrial component of this overall application;
- It is recommended that future monitoring should also focus on rare taxa such as Labeobarbus kimberleyensis in the Sand River; and
- Measures to improve or achieve the targets established are outlined in the risk assessment mitigation measures

Table 7-1: Monitoring Checklist for Harmony Free State Operations

Key Performance Indicator	Target	Location	Frequency of monitoring	Attenable Biomonitoring Target/limits					
				Merriespruit River	Mahem River	Doring, Theronspruit & Bosluisspruit River	Rietspruit	Sand River	Sandspruit & Bosluisspruit River
Water quality	Salt concentrations must be at levels that do not threaten the ecosystem and are suitable for users. Dissolved organic carbon concentrations must not cause the ecosystem to become unsustainable. An appropriate chemical analysis program is recommended.	Current sites used in this assessment	Bi-annual (Winter & Summer Season)	pH between 6.5 – 8.5 Conductivity ≤ 650 µS/cm Dissolved Oxygen >5.00 mg/L Temperature (°C) between 5 - 30	pH between 6.5 – 8.5 Conductivity ≤ 700 µS/cm Dissolved Oxygen >5.00 mg/L Temperature (°C) between 5 - 30	pH between 7.5 – 9.2 Conductivity ≤ 700 µS/cm Dissolved Oxygen >5.00 mg/L Temperature (°C) between 5 - 30	pH between 6.5 – 9.2 Conductivity ≤ 850 µS/cm Dissolved Oxygen >5.00 mg/L Temperature (°C) between 5 - 30	pH between 6.5 – 9.2 Conductivity ≤ 850 µS/cm Dissolved Oxygen >5.00 mg/L Temperature (°C) between 5 - 30	pH between 6.5 – 8.5 Conductivity ≤ 700 µS/cm Dissolved Oxygen >5.00 mg/L Temperature (°C) between 5 - 30
Habitat Assessment	Instream habitat must be in a moderately modified or better condition to support the ecosystem.	Current sites used in this assessment	Bi-annual (Winter & Summer Season)	Instream Habitat Integrity category **≥ C (≥ 62)** Riparian Habitat Integrity category of **≥ C (≥ 60)**	Instream Habitat Integrity category **≥ D (≥ 50)** Riparian Habitat Integrity category of **≥ D (≥ 50)**	Instream Habitat Integrity category **≥ B (≥ 80)** Riparian Habitat Integrity category of **≥ C (≥ 70)**	Instream Habitat Integrity category **≥ C (≥ 60)** Riparian Habitat Integrity category of **≥ D (≥ 42)**	Instream Habitat Integrity category **≥ D (≥ 42)** Riparian Habitat Integrity category of **≥ D (≥ 42)**	Instream Habitat Integrity category **≥ D (≥ 50)** Riparian Habitat Integrity category of **≥ C (≥ 60)**
Macroinvertebrate Assessment	SASS5 & ASPT: No significant changes from established baseline conditions.	Current sites used in this assessment	Bi-annual (Winter & Summer Season)	≥ C (≥ 62)	≥ C (≥ 62)	≥ C (≥ 62)	≥ D (≥ 42)	≥ D (≥ 47)	≥ C (≥ 62)
Fish Community	At least 80% of the baseline fish community must be sampled.	Current sites used in this assessment	Bi-annual (Winter & Summer Season)		.	≥ D (≥ 42) In the Doring	≥ D (≥ 42)	≥ D (≥ 42)	≥ D (≥ 42)
EcoStatus	An EcoStatus of category C must be maintained, if not improved.	Current sites used in this assessment	Bi-annual (Winter & Summer Season)			D (Largely Modified)	D (Largely Modified)	D (Largely Modified)	D (Largely Modified)

Table 7-2: Selected methodology to be applied to each sampling site in future monitoring

Site	Watercourse type	In-situ water quality	Ex-situ Water Quality	SASS5	Fish	Diatoms
Rietspruit River						
SVC 03	River	✓	✓	✓	✓	✓
New CP ESW	River	✓	x	✓	✓	✓
Merriespruit River						
SVC 14	River	✓	x	x	x	x
Sand River						
SVC 01	River	✓	✓	✓	✓	✓
ESW 85	Instream Dam	✓	x	x	x	x
ESW 55	River	✓	x	✓	x	x
SVC 11	River	✓	x	✓	✓	x
SVC 10/Mostert 12/ ESW 54	River	✓	✓	✓	x	x
ESW 98	River	✓	x	x	x	x
SVC 08	River	✓	✓	✓	✓	✓
Mahem River						
ESW 17B	Instream Dam	✓	✓	x	x	x
ESW 14	Wetland	✓	x	x	x	✓
Mahem 4B	Instream Dam	✓	✓	x	x	x
ESW 73	Instream Dam	✓	x	x	x	x
ESW 101	Instream Dam	✓	x	x	x	x
ESW 100	Dam/Pan	✓	✓	x	x	x
Sandspruit River						
SVC 15	River	✓	✓	✓	x	✓
SVC 16	River	✓	x	✓	✓	x
SVC 17	River	✓	✓	✓	✓	✓
ESW 6	River	✓	x	x	x	x
ESW 1	River	✓	x	✓	x	✓
ESW 2	River/Wetland	✓	x	✓	x	x
Doring River						
SVC 12	River	✓	✓	✓	✓	✓
ESW 71	River	✓	x	x	x	x
ESW 82	River	✓	x	✓	✓	x
ESW 65	River	✓	x	x	x	x

SVC 04	River	✓	✓	✓	✓	✓
SVC 05	River	✓	x	✓	✓	x
ESW TK1	River	✓	x	x	x	x
SVC 07	River	✓	x	✓	✓	x
Bosluisspruit River						
SVC 06	River	✓	x	✓	x	x
Theronspruit River						
ESW 79	River	✓	x	x	x	x
ESW 80	River	✓	✓	✓	x	✓

8 Water Resource Risk Assessment

8.1 Current Impacts

The baseline assessment completed in this report indicates that ongoing mining activities are having a negative impact on the water resources of the project area. Impacts are associated with water quality perturbations as indicated by elevated salt concentrations and modifications of physical habitat through sedimentation, instream impoundments and flow modifications within the various catchments. These aspects result from an array of different infrastructure which fall within the 500 m regulated area of a watercourse. These different types of infrastructure are the focus of the risk assessment for each separate operation which constitute the Harmony Free State Operations. In order to investigate which activities require licensing due to their proximity within the regulated area of a watercourse, this was depicted in Figure 8-1, Figure 8-2, Figure 8-3, Figure 8-4, Figure 8-5, Figure 8-6 and Figure 8-7 for the five operations. Due to the sheer number of activities, the maps were created using the infrastructure codes from the existing permits and licences for the operations with a full key for the activities provided in Table 8-1.

Table 8-1: Key for the different activities occuring at each of the five Harmony Free State Operations.

Central Operations		Harmony One Operations		Harmony One Operations		Joel Operations		Saaiplaas Operations		Target Operations	
Code	Infrastructure	Code	Infrastructure	Code	Infrastructure	Code	Infrastructure	Code	Infrastructure	Code	Infrastructure
G1	70 Million Dam	A1	Masimong 4 Shaft	G45	FSN 2 Return Water Dam	A1	Joel 3 South Shaft	G1	D-Dam (Virginia)	A1	Target 1 Shaft
G2	Tweepan (Evaporation Dams)	A2	Bambanani East Shaft	G46	FSN 3A Slimes Dam Complex	F1	Joel Sewage Plant	G2	Video Evaporation Dams	A2	Target 3 Shaft
G3	Convent Dam (upper and lower)	A3	Unisel Shaft	G47	FSN 3B Slimes Dam Complex	G1	Joel Evaporation Dams	G3	Brand 1 Shaft Waste Rock Dump 1 & 2	G1	Million Gallon Dam
G4	Merriespruit 1 Shaft Waste Rock Dump	A4	Tshepong Shaft	G48	FSN 4 Slimes Dam	G2	Joel Stormwater Dam	G4	Brand 2 Shaft Waste Rock Dump	G2	Target 2 Shaft Evaporation Dam
G5	Merriespruit 3 Shaft Waste Rock Dump	A5	Nyala shaft	G49	FSN 5 Slimes Dam	G3	Joel 3 Shaft TK1 Water Dam	G5	Brand 3 Shaft Waste Rock Dump	G3	Target 3 Shaft Evaporation Dam
G6	Virginia 1 Shaft Waste Rock Dump	A6	Eland Shaft	G50	FSN 6 Slimes Dam	G4	Joel Sewage Plant	G6	Brand 5 Shaft Waste Rock Dump	G4	Emergency Overflow Ponds
G7	Virginia 2 Shaft Waste Rock Dump	A7	Witpan	G51	FSN 6 Return Water Dam	G5	Joel 3 South (Taung South) Shaft Waste Rock Dump	G7	Saaiplaas 2 Shaft Waste Rock Dump	G5	Target 3 Sewage Treatment Plant
G8	FSS5 Slimes Dam	A8	Witpan	G52	ARM (Welkom) Slimes Dam	G6	Joel 1 North (Taung North) Shaft Waste Rock Dump	G8	Saaiplaas 3 Shaft Waste Rock Dump	G6	Lorraine 1 New Waste Rock Dump
G9	Brand D Slimes Dam Complex	A9	Bambanani West Borehole	G53	Welkom Return Water Dam	G7	Joel Slime Dam Complex	G9	St Helena Waste Rock Dump	G7	Lorraine 1 Old Waste Rock Dump
G10	No. 22 (H1) Slimes Dam Complex	G1	Harmony One Plant Surge Dam/Stormwater Dam	G54	FSS1 Slimes Dam	G8	Joel Return Water Dam	G10	St Helena Waste Rock Dump 1	G8	Lorraine 2 Waste Rock Dump
G11	No. 23 (H4) Slimes Dam Complex	G2	D-Dam	G55	FSS2 Slime Dam	G9	Dust Suppression Joel 3 South (Taung South) Shaft Waste Rock Dump	G11	St Helena Waste Rock Dump 2	G9	Target 3 Shaft Waste Rock Dump (Lorraine 3)
G12	No 23 (H4) Return Water Dam	G3	Koffer Dam	G56	FSS3 Slimes Dam	G10	Dust Suppression Joel 1 South (Taung North) Shaft Waste Rock Dump	G12	St Helena No. 7 Waste Rock Dump	G10	Freddies 3 Shaft Waste Rock Dump
G13	Harmony A-Dam	G4	ARM Vlei	G57	FSS4 Slimes Dam	G11	Dust Suppression Joel Slime Dam Complex	G13	St Helena 8 Waste Rock Dump	G11	Freddies 6 Shaft Waste Rock Dump
G14	Harmony B-Dam	G5	Masimong 4 Hot Water Dam	G58	FSS6 Slimes Dam	J1	Joel 3 South Shaft	G14	St Helena No. 10 Waste Rock Dump	G12	Freddies 9 Shaft Waste Rock Dump

G15	Harmony C-Dam	G6	Doringpan Evaporation Dam	G59	FSS7 Slimes Dam			G15	St Helena 2 Shaft Waste Rock Dump	G13	Target 1 Tailings Storage Facility
G16	Harmony D-Dam	G7	Water Dam 31	G60	FSS8 E&W Slime Dam Complex			G16	St Helena 7 Shaft (Development) Waste Rock Dump	G14	Target 2 Tailings Storage Facility
G17	Calcine Slimes Dam 24	G8	Water Dam 32	G61	12A Return Water Dam			G17	Brand A Slimes Dam Complex	G15	Freddies 9 Shaft Slimes dam
G18	Calcine Slimes Dam 25	G9	Water Dam 33	G62	12B Return Water Dam			G18	Brand Return Water Dam	G16	Freddies 9 Dam
G19	Calcine Slimes Dam 26	G10	Unisel Shaft Return Water Dam	G63	12C Return Water Dam			G19	Saaiplaas Slimes Dam Complex (Slimes dam 1, 2 & 3)	G17	Freddies Return Water Dam
G20	Calcine Slimes Dam 27	G11	Wessel Pan	G64	13 Return Water Dam			G20	Saaiplaas Return Water Dams 1, & 2	G18	South-east Return Water Dam (new clay lined dam)
G21	No. 30A Slimes Dam	G12	Tshepong Shaft Dam	G65	Dust Suppression Bambanani West (President Steyn 3 Shaft) Waste Rock Dump to Dam 13			G21	Saaiplaas Slimes Dam Complex 4	G19	Blue Return Water Dam
G22	No. 30B Slimes Dam	G13	Tshepong Stormwater Dam	G66	Dust Suppression Sable Shaft Waste Rock Dump			G22	Saaiplaas Slimes Dam Complex 5a & 5b	G20	North-west (old) Return Water Dam
G23	No. 31 Slimes Dam	G14	Duncan Dam	G67	Dust Suppression ARM 1 Shaft Waste Rock Dump (Welkom 1)			G23	Saaiplaas Slimes Dam Complex 6	G21	Swart Pan
G24	No. 32 Slimes Dam	G15	Masons Vlei	G68	Dust Suppression ARM 2 Shaft Waste Rock Dump (Welkom 2 Shaft)			G24	Saaiplaas No. 3 Return Water Dam	G22	Dust Suppression Lorraine 1 New Waste Rock Dump
G25	No. 33A Slimes Dam	G16	3.7 Million Dam	G69	Dust Suppression ARM 4 Shaft Waste Rock Dump (Welkom 4 Shaft)			G25	Saaiplaas No. 5 Return Water Dam	G23	Dust Suppression Lorraine 1 Old Waste Rock Dump
G26	No. 33B Slimes Dam	G17	Two Million Dam	G70	Dust Suppression ARM 6 Shaft Waste Rock Dump A - Unwashed			G26	21/H3 Slimes Dam	G24	Dust Suppression Lorraine 2 Old Waste Rock Dump
G27	No. 34A Slimes Dam	G18	Eland Shaft Water Dam	G72	Dust Suppression ARM 7 Shaft			G27	St Helena 1,2,3 Slimes Dam Complex	G25	Dust Suppression Target 3 Shaft Waste Rock Dump (Lorraine 3)

G28	No. 33B Slimes Dam	G19	FSG 2 Sewage Treatment Plant	G71	Dust Suppression ARM 6 Shaft Waste Rock Dump B - Washed Waste Rock Dump (WH)			G28	St Helena 4 Return Water Dam	G26	Dust Suppression Freddies 3 Shaft Waste Rock Dump
G29	Dust Suppression Merriespruit 3 Shaft Waste Rock Dump	G20	Bambanani West (President Steyn 3#) Waste Rock Dump to Dam 13	G73	Dust Suppression Harmony 2 Shaft Waste Rock Dump			G29	St Helena 1,2,3 Return Water Dam	G27	Dust Suppression Freddies 6 Shaft Waste Rock Dump
G30	Dust Suppression Virginia 1 Shaft Waste Rock Dump	G21	Bambanani East (President Steyn 3 Shaft) Waste Rock Dump to Dam 13	G74	Dust Suppression Nyala Shaft Waste Rock Dump			G30	St Helena 1,2,3 Stormwater Dam	G28	Dust Suppression Freddies 9 Shaft Waste Rock Dump
G31	Dust Suppression Virginia 2 Shaft Waste Rock Dump	G22	Masimong 4 Waste Rock Dump	G75	Dust Suppression Tshepong Waste Rock Dump			G31	Dust Suppression Brand 1 Shaft Waste Rock Dump 1 & 2	G29	Dust Suppression Target 1 Tailings Storage Facility
G32	Dust Suppression FSS5 Slimes Dam	G23	Masimong 5 Waste Rock Dump	G76	Dust Suppression FSN 1 Slimes Dam			G32	Dust Suppression Brand 2 Shaft Waste Rock Dump	G30	Dust Suppression Target 2 Tailings Storage Facility
G33	Dust Suppression Brand D Slimes Dam Complex	G24	Sable Shaft Waste Rock Dump	G77	Dust Suppression FSN 2 Slimes Dam			G33	Dust Suppression Brand 3 Shaft Waste Rock Dump	G31	Dust Suppression Freddies 9 Shaft Slimes dam
G34	Dust Suppression No. 22 (H1) Slimes Dam Complex	G25	Western Holdings 5 Waste Rock Dump	G78	Dust Suppression FSN 4 Slimes Dam			G34	Dust Suppression Brand 5 Shaft Waste Rock Dump	J2	Target 3 Shaft
G35	Dust Suppression No. 23 (H4) Slimes Dam Complex	G26	ARM 1 Shaft Waste Rock Dump (Welkom 1)	G79	Dust Suppression FSN 5 Slimes Dam			G35	Dust Suppression Saaiplaas 2 Shaft Waste Rock Dump	J1	Target 1 Shaft
G36	Dust Suppression Calcine Slimes dam 24	G27	ARM 2 Shaft Waste Rock Dump (Welkom 2 Shaft)	G80	Dust Suppression on FSN 3A Slimes Dam Complex			G36	Dust Suppression Saaiplaas 3 Shaft Waste Rock Dump		
G37	Dust Suppression Calcine Slimes dam 25	G28	ARM 3 Shaft Waste Rock Dump (Welkom 3 Shaft)	G81	Dust Suppression FSN 3B Slimes Dam Complex			G37	Dust Suppression St Helena Waste Rock Dump		
G38	Dust Suppression Calcine Slimes Dam 26	G29	ARM 4 Shaft Waste Rock Dump (Welkom 4 Shaft)	G82	Dust Suppression FSN 6 Slimes Dam			G38	Dust Suppression St Helena Waste Rock Dump 1		
G39	Dust Suppression Calcine Slimes Dam 27	G30	ARM 6 Shaft Waste Rock Dump A - Washed	G83	Dust Suppression ARM (Welkom) Slimes Dam			G39	Dust Suppression St Helena Waste Rock Dump 2		
G40	Dust Suppression No. 30A Slimes Dam	G31	ARM 6 Shaft Waste Rock Dump B - Washed	G84	Dust Suppression FSS8 E&W Slime Dam Complex			G40	Dust Suppression St Helena No. 7 Waste Rock Dump		

G41	Dust Suppression No. 30B Slimes Dam	G32	ARM 7 Shaft Waste Rock Dump (WH)	G85	Dust Suppression FSS1 Slimes Dam			G41	Dust Suppression St Helena 8 Waste Rock Dump		
G42	Dust Suppression No. 31 Slimes Dam	G33	Harmony 2 Shaft Waste Rock Dump	G86	Dust Suppression FSS2 Slimes Dam			G42	Dust Suppression St Helena No. 10 Waste Rock Dump		
G43	Dust Suppression No. 32 Slimes Dam	G34	Harmony 4 Shaft Waste Rock Dump	G87	Dust Suppression FSS3 Slimes Dam			G43	Dust Suppression St Helena 7 Shaft (Development) Waste Rock Dump		
G44	Dust Suppression 33A Slimes Dam	G35	Unisel Waste Rock Dump	G88	Dust Suppression FSS4 Slimes Dam			G44	Dust Suppression Brand A Slimes Dam Complex		
G45	Dust Suppression No. 33B Slimes Dam	G36	WRD 12 (H3A) Waste Rock Dump	G89	Dust Suppression FSS6 Slimes Dam			G45	Dust Suppression Slimes Dam Complex (Slimes dam 1, 2 & 3)		
G46	Dust Suppression No. 34 A Slimes Dam	G37	WRD 13 (H3B) Waste Rock Dump	G90	Dust Suppression FSS7 Slimes Dam			G46	Dust Suppression Saaiplaas Slimes Dam Complex 4		
G47	Dust Suppression No. 34 B Slimes Dam	G38	Eland Shaft Waste Rock Dump	J1	Masimong 4 Shaft			G47	Dust Suppression Saaiplaas Slimes Dam Complex 5a & 5b		
		G39	Kudu Shaft Waste Rock Dump	J2	Bambanani East Shaft			G48	Dust Suppression Saaiplaas Slimes Dam Complex 6		
		G40	Nyala Shaft Waste Rock Dump	J3	Unisel Shaft			G49	Dust suppression 21/H3 Slimes Dam		
		G41	Tshepong Waste Rock Dump	J4	Tshepong Shaft			G50	Dust Suppression St Helena 1,2,3 Slimes Dam Complex		
		G42	FSN 1 Slimes Dam	J5	Nyala shaft						
		G43	FSN 1 Return Water Dam	J6	Eland Shaft						
		G44	FSN 2 Slimes Dam								

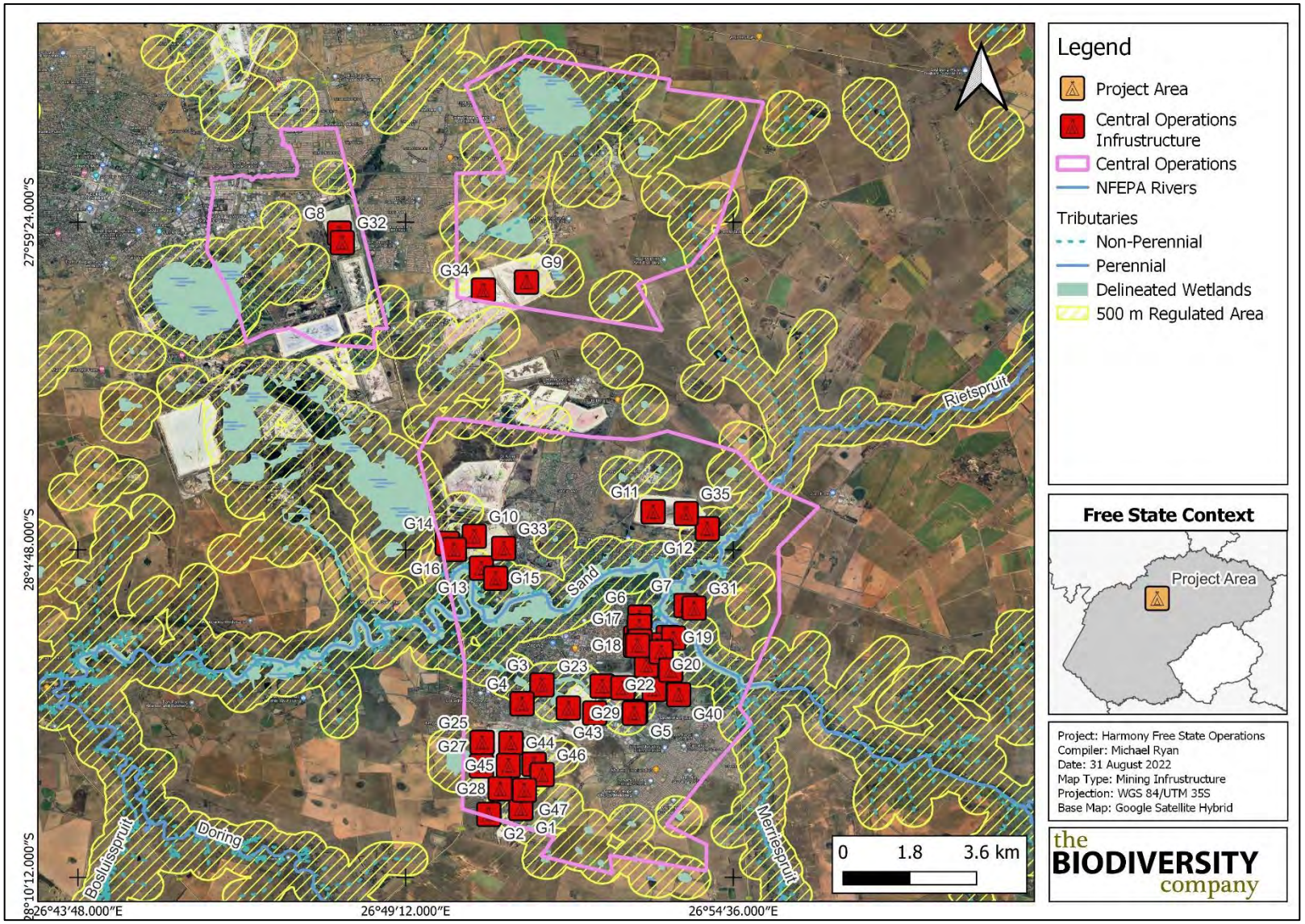


Figure 8-1: Depiction of all infrastructure within the 500 m regulated area at Central Operations

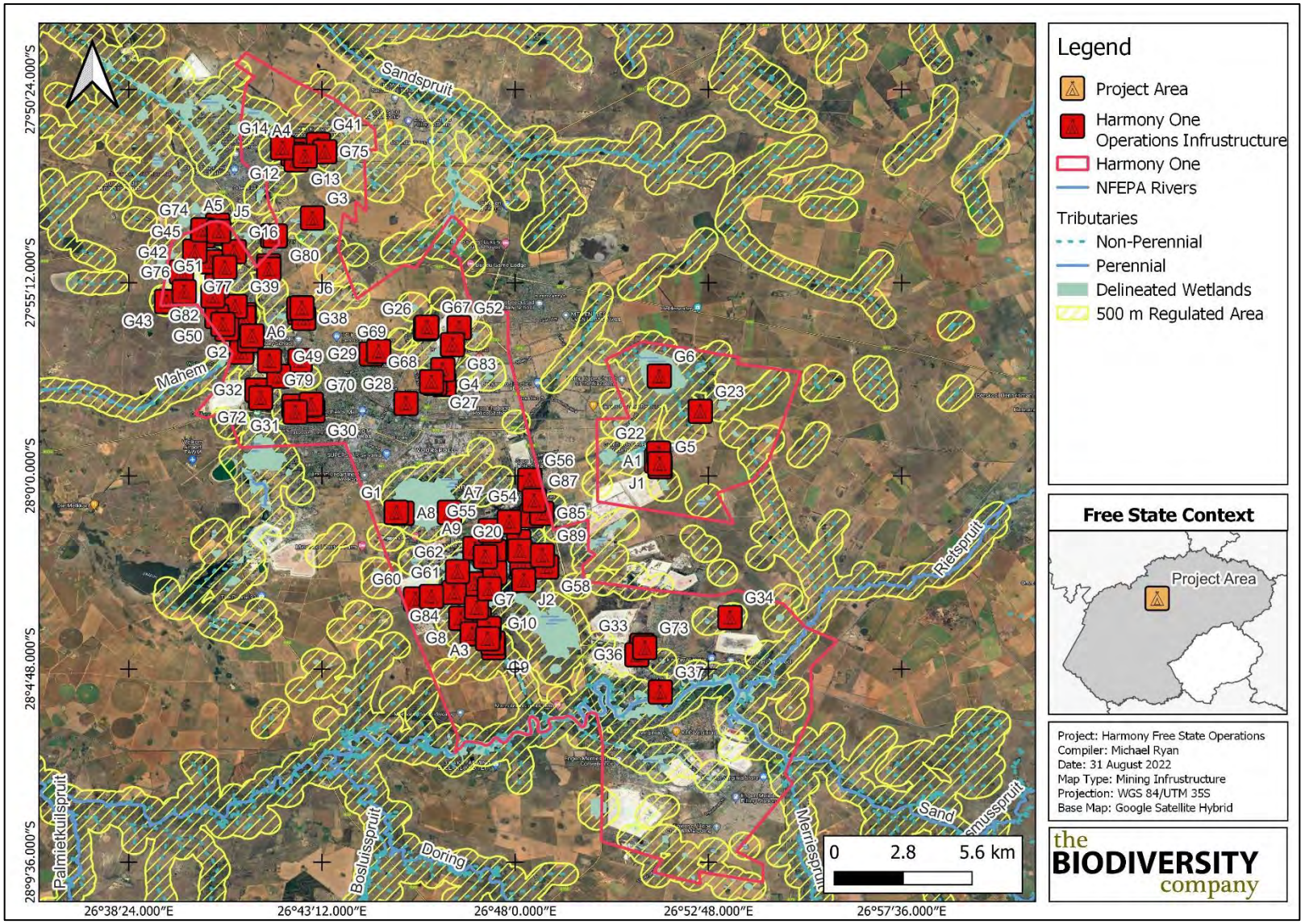


Figure 8-2: Depiction of all infrastructure within the 500 m regulated area at Harmony One Operations

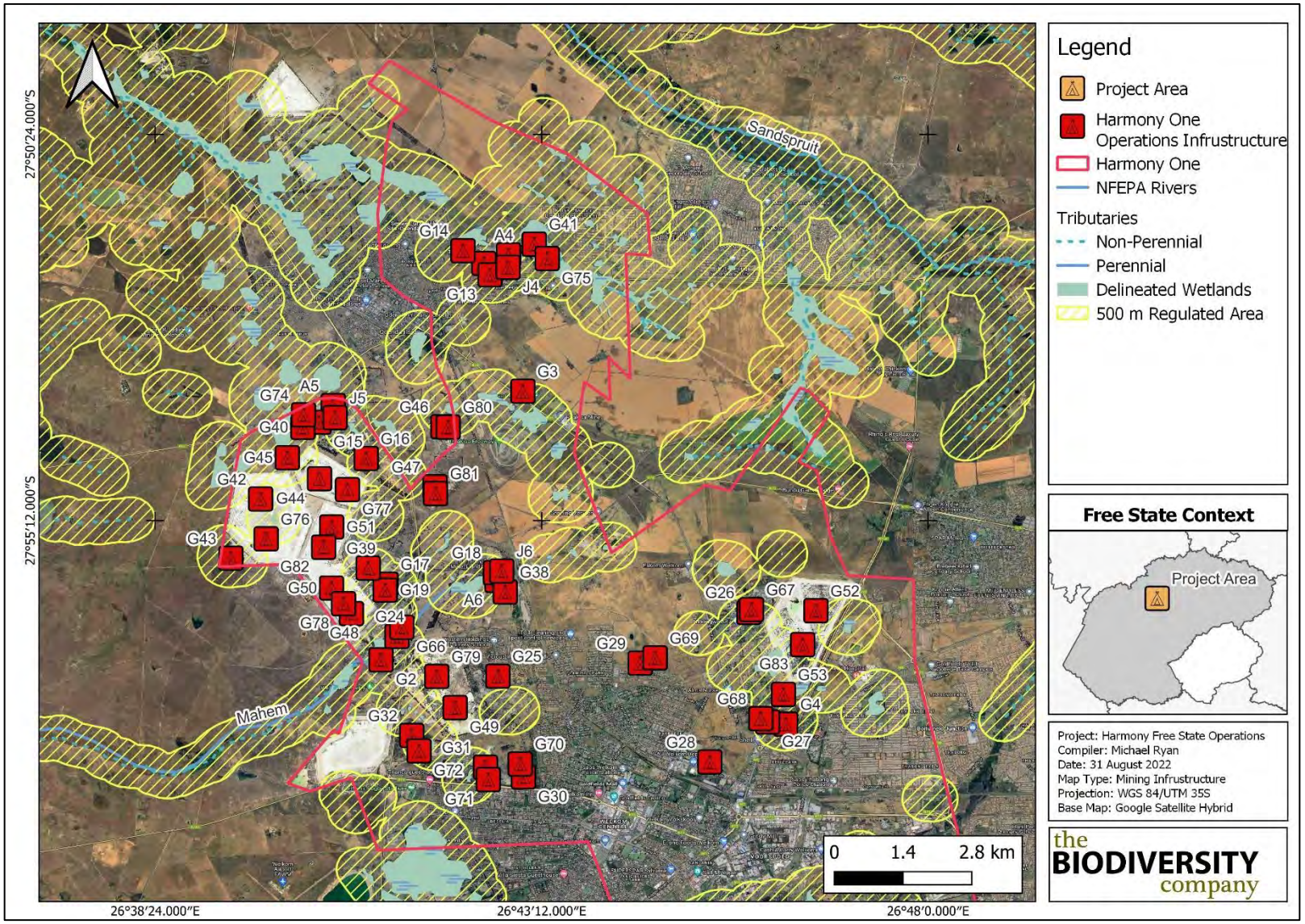


Figure 8-3: Zoomed in depiction of all infrastructure within the 500 m regulated area at Harmony One Operations northern section

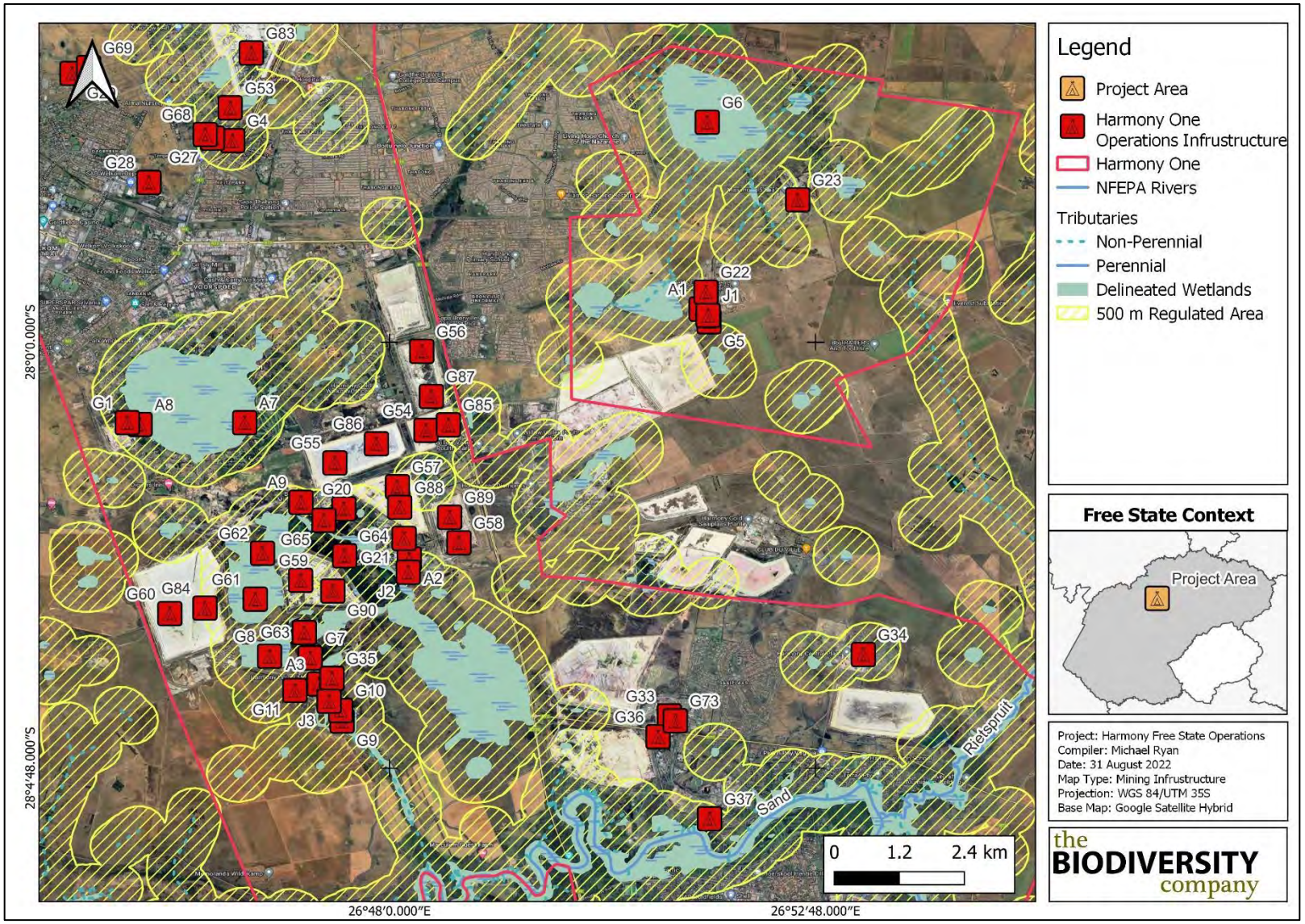


Figure 8-4: Zoomed in depiction of all infrastructure within the 500 m regulated area at Harmony One Operations southern section

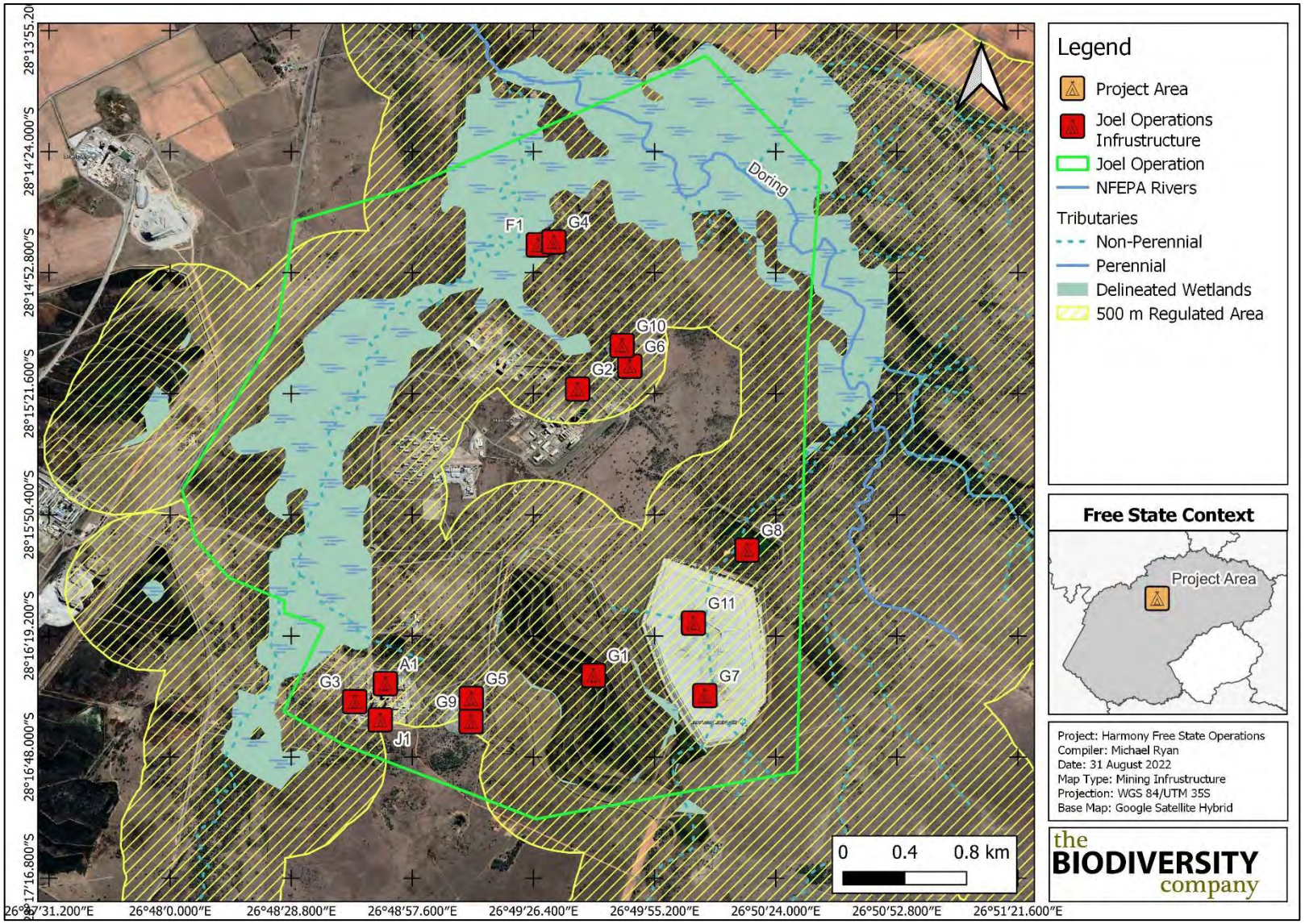


Figure 8-5: Depiction of all infrastructure within the 500 m regulated area at Joel Operations

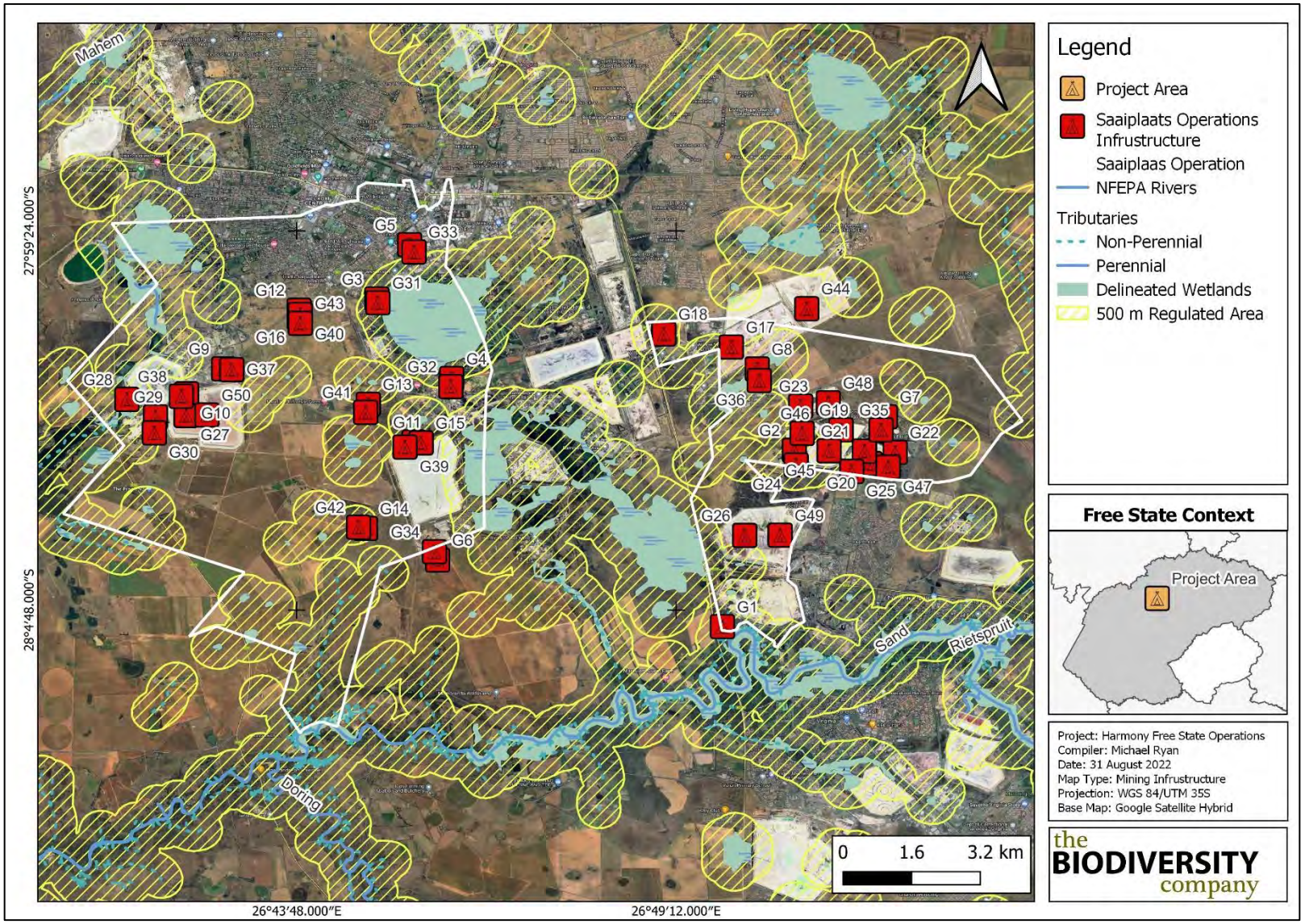


Figure 8-6: Depiction of all infrastructure within the 500 m regulated area at Saaiplaas Operations

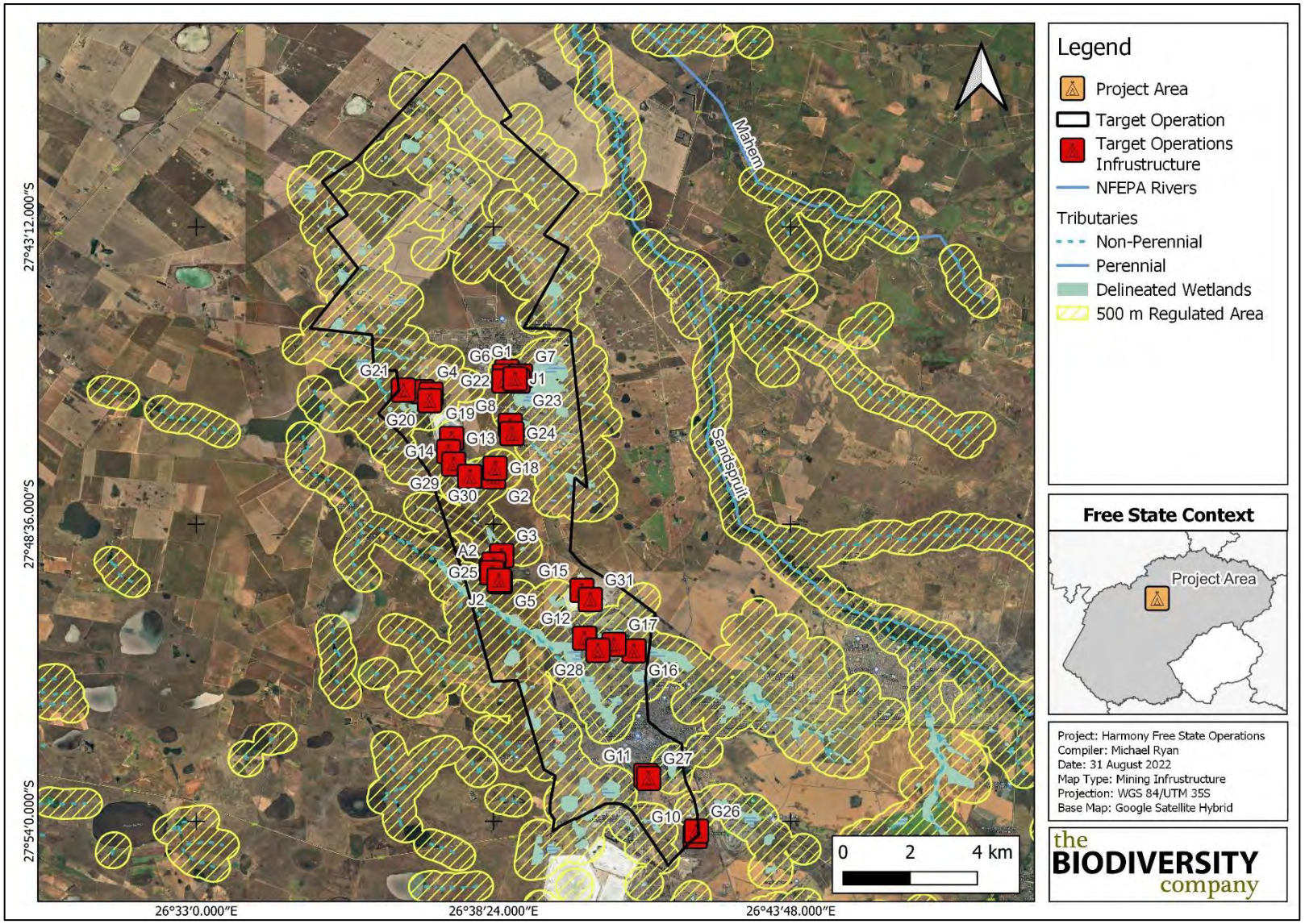


Figure 8-7: Depiction of all infrastructure within the 500 m regulated area at Target Operations

8.2 Risk Assessment

A risk assessment was conducted in line with Section 21 (c) and (i) of National Water Act (Act 36 of 1998) (NWA) to investigate the level of risk posed by the mining project. During the development of the risk matrix the focus was on the current existing mining activity (underground mining) and existing mining related infrastructure (on the surface). With the current mine layout, numerous activities occur within the 500 m regulated area of the delineated watercourses. Table 8-2 lists the potential risks posed by the existing mining activities to the delineated water resources.

The impacts listed in Table 8-2 have the potential to comprise the drivers and responders of the system, with the following water resource features potentially be compromised:

- Indirect loss of wetlands;
- Instream sedimentation;
- Loss of biodiversity;
- Loss of aquatic biota;
- Loss of aquatic vegetation;
- Water quality impairment;
- Bioaccumulation of heavy metals;
- Drainage patterns change; and
- Altering overland flow characteristics.

It should be noted during the underground mining and related operations the impact mitigation hierarchy was considered (Figure 8-8). Due to the historicity of the activities occurring on the mine with the current WULA for all existing infrastructure updating the existing previous valid permits / licences under Act 54 of 1956, which comprise the five separate operations of the Harmony Free State Operations, only the operational phase of the activities was considered. As the large number of the water resources occurring within the project area have not been directly impacted by the mining operations up to date, as they were constructed outside of the 500 m regulated area. There were however those areas which were avoidable, where mining related infrastructure traverses these watercourses. This show the avoid aspect of the mitigation hierarchy was considered where possible. Due to the nature of the project with multiple aspects representing legacy issues of pollution, and every aspect being applied for already constructed infrastructure, mitigation and rehabilitation is limited, with a comprehensive rehabilitation plan suggested to be drafted for the decommissioning phase of the mining operations. Mitigation measures have been suggested in an attempt to minimize ongoing environmental issues (Table 8-2). Despite the indication of certain mitigations only applying where feasible, this is not considered licence to ignore the prescribed measures and a significant effort should be made by the mine to realise all the prescribed mitigation measures.

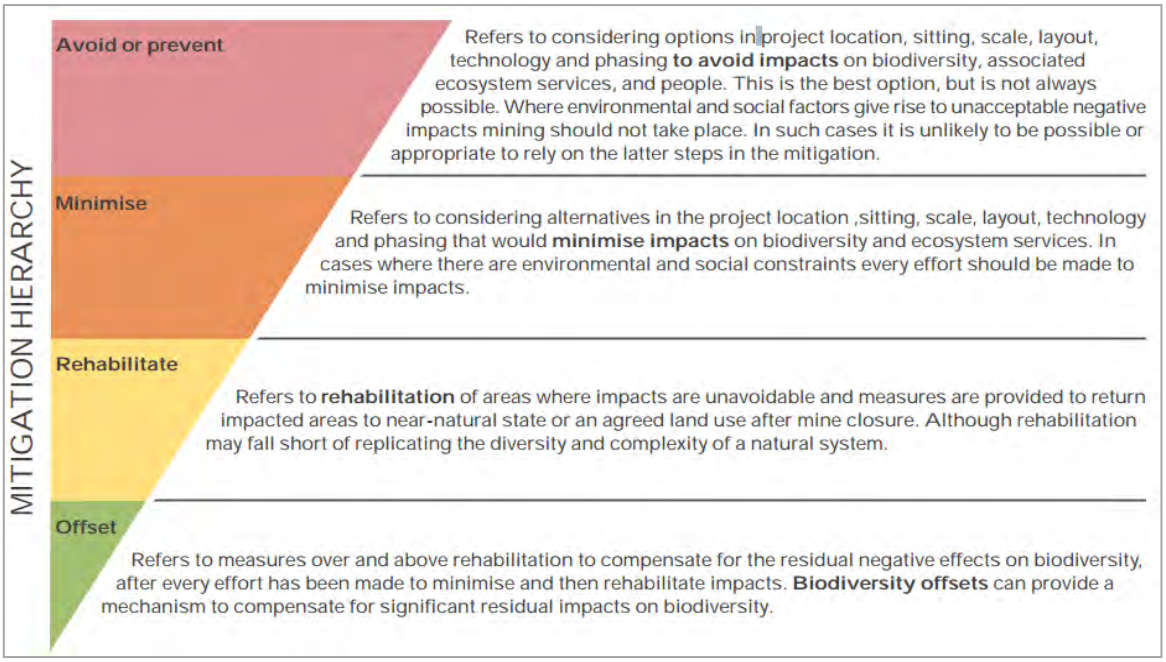


Figure 8-8: The mitigation hierarchy as described by the DEA (2013)

Table 8-2 illustrates the potential aspects expected to threaten the integrity of sensitive receptors during the proposed activities. The pre- and post- mitigation significance ratings have been calculated considering various parameters, these results are presented in the subsequent tables for each mining operational area are presented in:

- Saaiplaas Operational Area: Table 8-3;
- Central Operational Area Table 8-4;
- Harmony One Table 8-5;
- Joel Operational Area Table 8-6; and
- Target Operational Area Table 8-7.

The findings from the risk assessment indicate various aspects scored “Moderate” and “High” pre-mitigation significance ratings. Some of these aspects are expected to still be “Moderate” and “High” after mitigation due to the continued contamination of the watercourse through surface and groundwater systems and elevated risks these activities pose to the water resources within the project area.

Table 8-2: Aspects and impacts relevant to the activity

Phase	Activity	Aspect	Impact	Mitigation Measures
Operation of Mine	Operation of clean and dirty water systems	Dirty water facilities (Pollution Control Dams, Return Water Dams) In-channel Clean water impoundment Off-channel clean water impoundment	The potential failure of the PCD infrastructure may result in leakages and possible contamination of surface and groundwater, increased flow into the watercourses, and lowered water quality (increase in salts and specific contaminants of concern and reduced pH) within the watercourses.	Proactive monitoring to ensure structural integrity is maintained; It is recommended that the infrastructure be regularly inspected for leaks, or more often should there be any sign or reports of a leak; Should leakage occur all possible steps are to be taken to prevent the pollution of the downgradient wetlands systems during repair; and All discharges should be managed according to the Direct Estimation of Ecological Effect Potential (DEEEP) method if unavoidable.
	Stockpiles and surface storage of waste materials	Slimes Dam Complex Waste Rock Dump Tailings Facilities	Runoff during high rainfall events has the potential to result in sedimentation of water resources and the contamination of wetlands and water courses.	Where feasible, stockpiles and hazardous waste storage areas must be bunded by either a cut-off trench directed to a PCD or via a berm. A sediment trap must be installed at the PCD and be regularly maintained to ensure the freeboard is maintained.
	Maintenance of the existing surface infrastructure such as office buildings, workshops, fences, roads and pipelines.	Operation of infrastructure associated with shafts and access	The operation of the ancillary infrastructure will impact the surrounding watercourses via direct runoff from hardened surfaces and materials from stockpiles and workshops. This runoff will likely contain contaminants and occur at elevated velocities. Impacts to be expected in this phase can largely be related to water quality and quantity impacts.	Adequate stormwater infrastructure is required to separate clean and dirty water. Where feasible, clean water discharge into the environment should have energy dissipaters to reduce the potential of erosion during high rainfall events and subsequent sheet runoff.
	Operation of the underground mining areas	Underground mining	Potential destabilization of surrounding environment through the further excavation of underground mining corridors and subsequent potential subsidence of the land.	Underground mining closer to the surface should be carried out with extreme caution to ensure that the subsurface process sustaining the wetland systems are not impaired: Ensure that future shallow underground mining areas are located outside of the wetland recharge soils; Any areas where future decant points may be determined by a geohydrological assessment, need to be carefully managed throughout the life of the mine; Water levels need to be strictly managed to ensure they are kept below any decant level while ensuring that a significant cone of depression impact does not take place; and If decant does occur, all water is to be treated to the background water quality values prior to release into the receiving environment.

Phase	Activity	Aspect	Impact	Mitigation Measures
	Operation and maintenance of the stormwater management system associated with the existing mining activities.	Stormwater management	Loss of catchment yield resulting from stormwater containment, leading to: Increased flood peaks as a result of formalization and concentration of surface runoff in clean water diversion structures; Potential for erosion, leading to sedimentation of the watercourses; Reduction in volume of water entering the watercourses, leading to loss of recharge of the watercourses; Altered vegetation community structure and diversity due to moisture stress and changes to goods and service provision.	Clean and dirty water systems must be kept separate in line with Regulation GN704; Where feasible, runoff from areas within the dirty water area should be captured in the sump and pumped to a PCD that is lined with an appropriate liner, before being re-used as process water of the mine, therefore all future PCD's must be lined; Where feasible, all clean water diversions should be designed to accommodate the peak flow expected for at least a 1:50 year event; Where feasible, the stormwater outlet should be constructed from energy dissipating structures (such as Armorflex or reno mattresses) to slow down the velocity of water inflow into the wetland; and After construction of the outlet, the area surrounding the outlet should be re-seeded with indigenous wetland vegetation.
	Operation of Sewage Treatment Works	Discharge of water	Potential discharge of untreated water or water that does not meet required standards resulting in water quality perturbations, downstream nitrification. Increased flows resulting in habitat modification and erosion.	All discharged water is required to meet stipulated water quality guidelines. Energy dissipaters is required as the outfall to negate erosion and downstream sedimentation and should be installed if not already in place. Routine monitoring of outfall is required.

Table 8-3: DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Saaiplaas Operational Area

Aspect	Flow Regime	Physico & Chemical (Water Quality)	Habitat (Geomorph + Vegetation)	Biota	Severity	Spatial scale	Duration	Consequence
Dirty Water Facilities (Pollution Control Dams, Return Water Dams)	1	5	3	5	3,5	3	4	10,5
In-Channel Clean Water Impoundment	4	2	5	4	3,75	2	4	9,75
Off-Channel Clean Water Impoundment	3	2	1	2	2	2	4	8
Slimes Dam Complex	4	5	5	5	4,75	3	5	12,75
Waste Rock Dump	2	4	4	4	3,5	3	4	10,5
Operation of Underground Mining Areas	3	2	3	3	2,75	2	3	7,75
Stormwater Management	4	4	3	3	3,5	2	2	7,5
Maintenance of Roads and Traffic	2	3	3	3	2.75	3	3	8.75

DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Saaiplaas Operational area continued…

Aspect	Frequency of activity	Frequency of impact	Legal Issues	Detection	Likelihood	Significance	Risk Rating Pre-Mitigation	Post Mitigation
Dirty Water Facilities (Pollution Control Dams, Return Water Dams)	5	3	5	3	16	168	Moderate	Moderate
In-Channel Clean Water Impoundment	5	3	5	2	15	146,25	Moderate	Moderate
Off-Channel Clean Water Impoundment	4	2	1	2	9	72	Moderate	Low
Slimes Dam Complex	5	4	5	4	18	229,5	High	High
Waste Rock Dump	5	3	5	2	15	157,5	Moderate	Moderate
Operation of Underground Mining Areas	5	3	5	3	16	124	Moderate	Moderate
Stormwater Management	3	3	5	3	14	105	Moderate	Moderate
Maintenance of Roads and Traffic	2	3	1	3	9	78.75	Moderate	Low

(*) denotes - In accordance with General Notice 509 “Risk is determined after considering all listed control / mitigation measures. Borderline Low / Moderate risk scores can be manually adapted downwards up to a maximum of 25 points (from a score of 80) subject to listing of additional mitigation measures detailed below.

Table 8-4: DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Central Operational Area

Aspect	Flow Regime	Physico & Chemical (Water Quality)	Habitat (Geomorph + Vegetation)	Biota	Severity	Spatial scale	Duration	Consequence
Dirty Water Facilities (Pollution Control Dams, Return Water Dams)	1	5	3	5	3,5	3	4	10,5
In-Channel Clean Water Impoundment	4	2	5	4	3,75	2	4	9,75
Off-Channel Clean Water Impoundment	3	2	1	2	2	2	4	8
Slimes Dam Complex	4	5	5	5	4,75	3	5	12,75
Waste Rock Dump	2	4	4	4	3,5	3	4	10,5
Operation of Underground Mining Areas	3	2	3	3	2,75	2	3	7,75
Stormwater Management	4	4	3	3	3,5	2	2	7,5
Maintenance of Roads and Traffic	2	3	3	3	2.75	3	3	8.75

DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Central Operational Area continued…

Aspect	Frequency of activity	Frequency of impact	Legal Issues	Detection	Likelihood	Significance	Risk Rating Pre-Mitigation	Post Mitigation
Dirty Water Facilities (Pollution Control Dams, Return Water Dams)	5	3	5	3	16	168	Moderate	Moderate
In-Channel Clean Water Impoundment	5	3	5	2	15	146,25	Moderate	Moderate
Off-Channel Clean Water Impoundment	4	2	1	2	9	72	Moderate	Low
Slimes Dam Complex	5	4	5	4	18	229,5	High	High
Waste Rock Dump	5	3	5	2	15	157,5	Moderate	Moderate
Operation of Underground Mining Areas	5	3	5	3	16	124	Moderate	Moderate
Stormwater Management	3	3	5	3	14	105	Moderate	Moderate
Maintenance of Roads and Traffic	2	3	1	3	9	78.75	Moderate	Low

(*) denotes - In accordance with General Notice 509 "Risk is determined after considering all listed control / mitigation measures. Borderline Low / Moderate risk scores can be manually adapted downwards up to a maximum of 25 points (from a score of 80) subject to listing of additional mitigation measures detailed below.

Table 8-5: DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Harmony Operational Area

Aspect	Flow Regime	Physico & Chemical (Water Quality)	Habitat (Geomorph + Vegetation)	Biota	Severity	Spatial scale	Duration	Consequence
Dirty Water Facilities (Pollution Control Dams, Return Water Dams)	1	5	3	5	3,5	3	4	10,5
In-Channel Clean Water Impoundment	4	2	5	4	3,75	2	4	9,75
Off-Channel Clean Water Impoundment	3	2	1	2	2	2	4	8
Slimes Dam Complex	4	5	5	5	4,75	3	5	12,75
Waste Rock Dump	2	4	4	4	3,5	3	4	10,5
Operation of Underground Mining Areas	3	2	3	3	2,75	2	3	7,75
Stormwater Management	4	4	3	3	3,5	2	2	7,5
Maintenance of Roads and Traffic	2	3	3	3	2,75	3	3	8,75
Operation of Sewage Treatment Works	3	4	3	4	3,5	3	4	10,5
Shaft Associated Infrastructure	2	3	3	3	2,75	3	4	9,75

DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Harmony Operational Area continued…

Aspect	Frequency of activity	Frequency of impact	Legal Issues	Detection	Likelihood	Significance	Risk Rating Pre-Mitigation	Post Mitigation
Dirty Water Facilities (Pollution Control Dams, Return Water Dams)	5	3	5	3	16	168	Moderate	Moderate
In-Channel Clean Water Impoundment	5	3	5	2	15	146,25	Moderate	Moderate
Off-Channel Clean Water Impoundment	4	2	1	2	9	72	Moderate	Low
Slimes Dam Complex	5	4	5	4	18	229,5	High	High
Waste Rock Dump	5	3	5	2	15	157,5	Moderate	Moderate
Operation of Underground Mining Areas	5	3	5	3	16	124	Moderate	Moderate
Stormwater Management	3	3	5	3	14	105	Moderate	Moderate

Maintenance of Roads and Traffic	2	3	1	3	9	78,75	Moderate	Low
Operation of Sewage Treatment Works	4	3	5	3	15	157,5	Moderate	Moderate
Shaft Associated Infrastructure	3	3	1	3	10	97,5	Moderate	Moderate

(*) denotes - In accordance with General Notice 509 “Risk is determined after considering all listed control / mitigation measures. Borderline Low / Moderate risk scores can be manually adapted downwards up to a maximum of 25 points (from a score of 80) subject to listing of additional mitigation measures detailed below.

Table 8-6: DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Joel Operations

Aspect	Flow Regime	Physico & Chemical (Water Quality)	Habitat (Geomorph + Vegetation)	Biota	Severity	Spatial scale	Duration	Consequence
Dirty Water Facilities (Pollution Control Dams, Return Water Dams)	1	5	3	5	3,5	3	4	10,5
In-Channel Clean Water Impoundment	4	2	5	4	3,75	2	4	9,75
Off-Channel Clean Water Impoundment	3	2	1	2	2	2	4	8
Slimes Dam Complex	4	5	5	5	4,75	3	5	12,75
Waste Rock Dump	2	4	4	4	3,5	3	4	10,5
Operation of Underground Mining Areas	3	2	3	3	2,75	2	3	7,75
Stormwater Management	4	4	3	3	3,5	2	2	7,5
Maintenance of Roads and Traffic	2	3	3	3	2,75	3	3	8,75
Operation of Sewage Treatment Works	3	4	3	4	3,5	3	4	10,5
Shaft Associated Infrastructure	2	3	3	3	2,75	3	4	9,75

DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Joel Operations continued…

Aspect	Frequency of activity	Frequency of impact	Legal Issues	Detection	Likelihood	Significance	Risk Rating Pre-Mitigation	Post Mitigation
Dirty Water Facilities (Pollution Control Dams, Return Water Dams)	5	3	5	3	16	168	Moderate	Moderate
In-Channel Clean Water Impoundment	5	3	5	2	15	146,25	Moderate	Moderate
Off-Channel Clean Water Impoundment	4	2	1	2	9	72	Moderate	Low
Slimes Dam Complex	5	4	5	4	18	229,5	High	High
Waste Rock Dump	5	3	5	2	15	157,5	Moderate	Moderate
Operation of Underground Mining Areas	5	3	5	3	16	124	Moderate	Moderate
Stormwater Management	3	3	5	3	14	105	Moderate	Moderate

Maintenance of Roads and Traffic	2	3	1	3	9	78,75	Moderate	Low
Operation of Sewage Treatment Works	4	3	5	3	15	157,5	Moderate	Moderate
Shaft Associated Infrastructure	3	3	1	3	10	97,5	Moderate	Moderate

(*) denotes - In accordance with General Notice 509 “Risk is determined after considering all listed control / mitigation measures. Borderline Low / Moderate risk scores can be manually adapted downwards up to a maximum of 25 points (from a score of 80) subject to listing of additional mitigation measures detailed below.

Table 8-7: DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Target Operations

Aspect	Flow Regime	Physico & Chemical (Water Quality)	Habitat (Geomorph + Vegetation)	Biota	Severity	Spatial scale	Duration	Consequence
Dirty Water facilities (Pollution Control Dams, Return Water Dams)	1	5	3	5	3,5	3	4	10,5
In-Channel Clean Water Impoundment	4	2	5	4	3,75	2	4	9,75
Off-Channel Clean Water Impoundment	3	2	1	2	2	2	4	8
Slimes Dam Complex	4	5	5	5	4,75	3	5	12,75
Waste Rock Dump	2	4	4	4	3,5	3	4	10,5
Operation of Underground Mining Areas	3	2	3	3	2,75	2	3	7,75
Stormwater Management	4	4	3	3	3,5	2	2	7,5
Maintenance of Roads and Traffic	2	3	3	3	2,75	3	3	8,75
Operation of Sewage Treatment Works	3	4	3	4	3,5	3	4	10,5
Shaft Associated Infrastructure	2	3	3	3	2,75	3	4	9,75
Tailings Storage Facility	3	5	4	5	4.25	3	5	12.5

DWS Risk Impact Matrix for the Water Use Associated Infrastructures for the Target Operations continued…

Aspect	Frequency of activity	Frequency of impact	Legal Issues	Detection	Likelihood	Significance	Risk Rating Pre-Mitigation	Post Mitigation
Dirty Water Facilities (Pollution Control Dams, Return Water Dams)	5	3	5	3	16	168	Moderate	Moderate
In-Channel Clean Water Impoundment	5	3	5	2	15	146,25	Moderate	Moderate
Off-Channel Clean Water Impoundment	4	2	1	2	9	72	Moderate	Low
Slimes Dam Complex	5	4	5	4	18	229,5	High	High
Waste Rock Dump	5	3	5	2	15	157,5	Moderate	Moderate
Operation of Underground Mining Areas	5	3	5	3	16	124	Moderate	Moderate

Stormwater Management	3	3	5	3	14	105	Moderate	Moderate
Maintenance of Roads and Traffic	2	3	1	3	9	78,75	Moderate	Low
Operation of Sewage Treatment Works	4	3	5	3	15	157,5	Moderate	Moderate
Shaft Associated Infrastructure	3	3	1	3	10	97,5	Moderate	Moderate
Tailings Storage Facility	5	4	5	4	18	220,5	High	High

(*) denotes - In accordance with General Notice 509 “Risk is determined after considering all listed control / mitigation measures. Borderline Low / Moderate risk scores can be manually adapted downwards up to a maximum of 25 points (from a score of 80) subject to listing of additional mitigation measures detailed below.

8.3 Unplanned Events

The planned activities will have anticipated impacts as discussed above; however, unplanned events may occur on any project and may have potential impacts which will need management. Table 8-8 is a summary of the findings of an unplanned event assessment from a water resource perspective. Note, not all potential unplanned events may be captured herein, and this must therefore be managed throughout all phases according to recorded pollution events.

Table 8-8: Summary of potential unplanned events that require attention

Unplanned Event	Potential Impact	Mitigation
Hydrocarbon spill into riverine habitat	Contamination of sediments and water resources associated with the spillage.	A spill response kit must be always available. The incident must be reported on and if necessary. An aquatic specialist must investigate the extent of the impact and provide rehabilitation recommendations.
Uncontrolled erosion	Sedimentation of downstream river reach.	Erosion control measures and monitoring programme must be put in place.
Subsidence	Hydrological modification and resultant riverine habitat quality deterioration.	Subsidence risk assessment, avoidance of high-risk areas, post closure subsidence monitoring. Should subsidence occur a suitable management plan must be investigated, this may include the construction of water diversion around subsidence areas to avoid surface water loss. The required mitigation would however be site specific.
Acid Mine Drainage	Severe water quality degradation	Water treatment, post closure water monitoring and water level management.

9 Conclusions

9.1 Watercourse

Conclusions have been made according to river systems as a result of the multiple operations as well as the multiple river systems shared between these operations. The report has presented baseline conditions of all associated river systems associated to the Harmony Free State Operations which has assisted in the determination of a suitable monitoring program for future sampling for the five separate operations. The river systems that were assessed for water quality only were done only to investigate their potential influence on systems within the project area and are summarized below. The listed operations and associated rivers include:

- Central Operations – Rietspruit River, Merriespruit River, Doring River, Sand River and Bosluisspruit River;
- Harmony One Operations – Rietspruit River, Mahem River, Sand River and Sandspruit River;
- Joel Operations – Doring River and Theronspruit River;
- Saaiplaas Operations – Rietspruit River, Mahem River, Sand River and – Doring River; and
- Target Operations – Sandspruit River and Losdoringspruit.

9.1.1 Rietspruit River

Water quality within the Rietspruit River indicated modified conditions with measured parameters outside of the prescribed TWQRs and RQOs. The modified water quality is noted by elevated EC in the system which is a result of upstream activities as elevated concentrations are noted upstream of the Harmony Free State Operations. However small increase is noted between SVC 03 and New CP ESW which is downstream of the TSF associated with the southern section of the Harmony One Operations. The results of the instream habitat assessment for the Rietspruit River indicated a category C or moderately modified habitat conditions; while the riparian habitat assessment indicated a category D or largely modified habitat conditions. SASS5 scores ranged from category B (largely natural) to category C (moderately modified). The increase in ASPT is attributed to habitat availability as water quality does not improve. MIRAI scores for the system were derived as largely modified (category D) while FRAI scores were derived as seriously modified (category E) which are a result of degraded water quality in the system. The calculated PES for the system was therefore largely to seriously modified (category D/E).

9.1.2 Doring River

Water quality within the Doring River indicated modified conditions with measured parameters outside of the prescribed TWQRs and RQOs. Upstream of the Joel Operation water quality was measured to be compliant; however, water quality from the Theronspruit River which flows through the western boundary of the Joel Operation in identified as the source of modification. The Theronspruit River experiences modification from both the neighbouring Beatrix Operations and the mining activity related to the Joel Operations. The results of the instream and riparian habitat assessment for the Doring River indicated a category D or largely modified habitat conditions. SASS5 scores ranged from category A (natural) to category C (moderately modified). Conditions upstream of the Joel Operations are considered natural with a degradation of the overall class of the system to largely natural downstream. The Theronspruit River identified as the source of modification was measured as moderately modified based on the macroinvertebrate community sampled. MIRAI scores for the system were derived as largely modified (category D); while FRAI scores were derived as seriously modified (category E). This was a result of all three drivers contributing to the modified macroinvertebrate communities (flow

modifications, habitat and water quality). The resultant PES for the Doring River was therefore calculated to be largely modified (category D).

9.1.3 Bosluisspruit River

Water quality within the Bosluisspruit River indicated modified conditions with measured parameters outside of the prescribed TWQR and RQO. This system was only assessed as a potential source of modification to the Doring River which it presented to be, with modification unrelated to the Harmony free state operations; but rather agricultural practices and alternative mining operations. SASS5 scores for the reach indicated category E/F which was a compounded result from modified water quality and poor habitat (14%). FRAI scores were derived as seriously modified (category E) with the only species sampled in the reach the alien Invasive *Gambusia affinis*.

9.1.4 Sand River

Water quality within the Sand River indicated modified conditions with measured parameters outside of the prescribed TWQR and RQO. The modified conditions are only observed downstream of the Central, Harmony One and Saaiplaas Operations which are suspected to have resulted in the modification of the system. The Rietspruit River and Doring River also present sources of modification to the system that are affected by upstream mining and agricultural activities. The results of the instream habitat assessment for the Sand River indicated a category D or largely modified habitat conditions; while the riparian habitat assessment indicates a category E or seriously modified habitat conditions. These are significantly affected by the surrounding land use of mining activity, agriculture and urban settlements. SASS5 scores ranged from category B (largely natural) to category E/F (seriously modified) and indicate an overall downstream degradation of the system with high abundances noted upstream. Site SVC 10/Mostert 12/ ESW 54, which presents a cumulative influence of upstream mining activity, is considered seriously modified (category E/F). MIRAI scores for the system were derived as largely modified (category D); while FRAI scores were derived as seriously modified (category E). This has resulted in the calculated PES of Largely to Seriously Modified (category D/E) of the system which is predominantly due to diminished water quality in the system.

9.1.5 Mahem River

Water quality within the Mahem River indicated modified conditions with measured parameters outside of the prescribed TWQRs and RQOs. Water quality throughout the reach and associated tributaries is modified and indicates a direct influence from associated mining activities from the Central, Harmony One and Saaiplaas operations. The results of the instream and riparian habitat assessment in the Mahem River indicated a category E or seriously modified habitat conditions in the watercourses and its tributaries. The modification to the system has resulted in the discontinuity of the river from the downstream Vet River. SASS5 scores for the system were a category E/F (seriously modified) which is a combination of habitat availability and modified water quality. There was no calculated PES for the Mahem river due to lack of surface flow and access to the reach.

9.1.6 Sandspruit River

Water quality within the Sandspruit River indicated modified conditions with measured parameters outside of the prescribed TWQRs and RQOs. The Sandspruit River doesn't indicate modification from the Target or Harmony One Operations; however, the recorded modification at SVC 17 is unknown. The noted modification within the Losdoringspruit is however directly attributed to the mining activity associated with the Freddie's Plant of the Target Operations. The results of the instream habitat assessment for the Sandspruit River indicated a category D or largely modified habitat conditions; while the riparian habitat assessment indicated a category C or moderately modified habitat conditions. Surrounding agriculture has a large influence on the system. SASS5 scores ranged from category B (largely natural) to category C (moderately modified). Both sites SVC 15 and SVC 16 indicate largely

natural conditions with a noted degradation found at SVC 17, further reinforcing no noted modification resulting from the Target or Harmony One Operations. MIRAI scores for the system were derived as largely modified (category D); while FRAI scores were derived as largely modified (category D). This was a result of flow and water quality modification and resulted in a calculated PES of a category D indicating largely modified conditions.

9.2 Risk Assessment

A variety of risks have been identified for the separate operations which constitute the Harmony Free State Operations according to the infrastructure relevant to the separate operations. Due to the nature of the operations applying for a WUL for existing infrastructure, only the operational phase of these projects was considered. These various aspects scored “Moderate” and “High” pre-mitigation significance ratings with some expected to remain “Moderate” and “High” after mitigation due to the continued contamination of the watercourse through surface and groundwater systems and the elevated risks these activities pose to the water resources within the project area. These risks can be minimally mitigated, however are unavoidable with many resulting from legacy issues. This highlights the importance of a comprehensive rehabilitation plan for the decommissioning phase of the separate mining operations

10 References

Barbour, M.T., Gerritsen, J. & White, J.S. 1996. Development of a stream condition index (SCI) for Florida. Prepared for Florida Department of Environmental Protection: Tallahassee, Florida.

Dallas, H.F. 1997. A preliminary evaluation of aspects of SASS5 (South African Scoring System) or the rapid bioassessment of water in rivers with particular reference to the incorporation of SASS5 in a national biomonitoring programme. South African Journal of Aquatic Science, 23: 79-94.

Dallas, H.F. 2007. River Health Programme: South African Scoring System (SASS) Data Interpretation Guidelines. Report produced for the Department of Water Affairs and Forestry (Resource Quality Services) and the Institute of Natural Resources.

Department of Water and Sanitation (DWS). 2019. Determination of Water Resource Classes and Resource Quality Objectives for Mokolo, Matlabas, Crocodile (West) and Marico Catchments. Notice 526 of 2019. Government Gazette: No:42775. 18 October 2019

Department of Water Affairs and Forestry (DWAF) 2005. Final draft: A practical field procedure for identification and delineation of wetlands and Riparian areas.

Department of Environment, Forestry and Fisheries (DEFF), 2022. Screening Report for an Environmental Authorization or for a Part Two Amendment of an Environmental Authorisation as Required by the 2014 EIA Regulations – Proposed Site Environmental Sensitivity

Department of Water and Sanitation. 2014. A Desktop Assessment of the Present Ecological State, Ecological Importance and Ecological Sensitivity per Sub Quaternary Reaches for Secondary Catchments in South Africa. Secondary: C23K. Compiled by RQIS-RDM: https://www.dwa.gov.za/iwqs/rhp/eco/peseismodel.aspx. Accessed on 05 February 2022.

Department of Water Affairs (DWA). 2011. Procedures to Develop and Implement Resource Quality Objectives. Department of Water Affairs, Pretoria, South Africa

Republic of South Africa (RSA) 2016. Classes and resource quality objectives of water resources for catchment of the Middle Vaal. 22. No. 39943. Published in Government Gazette No. 469 dated 22 April 2016.

Dickens, C. W. S. and Graham, P.M. 2002. The South African Scoring System (SASS) Version 5: Rapid bioassessment method for rivers. African Journal of Aquatic Science. 27 (1): 1 -10.

Gerber, A. & Gabriel, M.J.M. 2002. Aquatic Invertebrates of South African Rivers Field Guide. Institute for Water Quality Studies. Department of Water Affairs and Forestry. 150pp

International Union for Conservation of Nature (IUCN) 2021. The IUCN Red List of Threatened Species. Version 2020-3. https://www.iucnredlist.org. Accessed 17 March 2021

Kleynhans CJ, Louw MD. 2007. Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Resource Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 329/08.

Kleynhans, CJ. 1996. A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu River (Limpopo System, South Africa) Journal of Aquatic Ecosystem Health 5:41-54.

Kotze DC, Marneweck GC, Batchelor AL, Lindley DC, Collins NB. 2009. A Technique for rapidly assessing ecosystem services supplied by wetlands. Mondi Wetland Project.

Macfarlane., D M and Bredin., I. 2017. Buffer zone Guidelines for Wetlands, River and Estuaries Part 1: Technical Manual

Macfarlane, D.M., Dickens J., Von Hase F. 2009. Development of a methodology to determine the appropriate buffer zone width and type for developments associated with wetlands, watercourses and estuaries. Final literature review. Report produced for the Department of Water Affairs and Forestry. Submitted to: Water Research Commission. INR Report No:400/09

Mucina, L. & Rutherford, M.C. (Eds.). (2006). The vegetation of South Africa, Lesotho and Swaziland. Strelizia 19. South African National Biodiversity Institute, Pretoria South African.

National Water Act (NWA). 2016. Act 36 of 1998. New Nine (9) Water Management Areas of South Africa. National Gazettes, No. 40279 of 16 September 2016

Nel, J. L., Driver, A., Strydom, W. F., Maherry, A. M., Petersen, C. P., Hill, L., Roux, D. J., Nienaber, S., van Deventer, H., Swartz, E. R. & Smith-Adao, L. B. (2011). Atlas of Freshwater Ecosystem Priority Areas in South Africa: Maps to support sustainable development of water resources, WRC Report No. TT 500/11. Water Research Commission, Pretoria.

Nel JL, Murray KM, Maherry AM, Petersen CP, Roux DJ, Driver A, Hill L, Van Deventer H, Funke N, Swartz ER, Smith-Adao LB, Mbona N, Downsborough L and Nienaber S. 2011. Technical Report for the National Freshwater Ecosystem Priority Areas project. WRC Report No. K5/1801.

Ollis DJ, Snaddon CD, Job NM, and Mbona N. 2013. Classification System for Wetlands and other Aquatic Ecosystems in South Africa. User Manual: Inland Systems. SANBI Biodiversity Series 22. South African Biodiversity Institute, Pretoria.

Rowntree, K. and Ziervogel, G., 1999. Development of an Index of Stream Geomorphology for the Assessment of River Health. National Aquatic Ecosystem Biomonitoring Programme.

Rountree KM, Wadeson RA and O'Keeffe J. 2000. The Development of a Geomorphological Classification System for the Longitudinal Zonation of South African Rivers. South African Geographical Journal 82 (3): 163-172.

SANBI. (2017). Technical guidelines for CBA Maps: Guidelines for developing a map of Critical Biodiversity Areas & Ecological Support Areas using systematic biodiversity planning. Driver, A., Holness, S. & Daniels, F. (Eds). 1st Edition. South African National Biodiversity Institute, Pretoria.

Soil Classification Working Group. (1991). Soil Classification A Taxonomic system for South Africa. Pretoria: The Department of Agricultural Development.

Soil Classification Working Group. (2018). Soil Classification A Taxonomic system for South Africa. Pretoria: The Department of Agricultural Development.

South African National Biodiversity Institute (SANBI). 2020. Species Environmental Assessment Guideline. Guidelines for the implementation of the Terrestrial Fauna and Terrestrial Flora Species Protocols for environmental impact assessments in South Africa. South African National Biodiversity Institute, Pretoria. Version 1.2020.

Skelton, P.H. (2001). A complete guide to the freshwater fishes of southern Africa. Struik Publishers, South Africa.

SRK Consulting 2020a. Harmony Gold – Central Operations. Integrated Water and Waste Management Plan in Support of the Water Use Licence Application. Report Number 548500/Central WULA

SRK Consulting 2020b. Harmony Gold – Harmony 1 Operations. Integrated Water and Waste Management Plan in Support of the Water Use Licence Application. Report Number 548500/Harmony 1 WULA

SRK Consulting 2020c. Harmony Gold – Joel Operations. Integrated Water and Waste Management Plan in Support of the Water Use Licence Application. Report Number 548500/Joel WULA

SRK Consulting 2020d. Harmony Gold – Saaiplaas Operations. Integrated Water and Waste Management Plan in Support of the Water Use Licence Application. Report Number 548500/Saaiplaas WULA

SRK Consulting 2020e. Harmony Gold – Target Operationss. Integrated Water and Waste Management Plan in Support of the Water Use Licence Application. Report Number 548500/Target WULA

Tate RB, Husted A. 2015. Aquatic macroinvertebrate responses to pollution of the Boesmanspruit river system above Carolina, South Africa. *African Journal of Aquatic Science*. 1-11.

Thirion, C. A. 2007. Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. Pretoria, South Africa: Department of Water Affairs and Forestry.

Wepener V, Van Vuren JHJ, Chatiza FP, Mbizi Z, Slabbert L, Masola B. 2005. Active biomonitoring in freshwater environments: early warning signals from biomarkers in assessing biological effects of diffuse sources of pollutants. Physics and Chemistry of the Earth 30: 751–761.

Appendix C: Public Participation Process Report

Quantity Report:
Water Balance

Joel Operations

31 August 2024

Generated on 04 October 2024

Report verification

Document control

ETA Personnel

	Name	Tel	Email
Compiled by	Nicholas Fernandes	078 488 4084	nfernandes@rems2.com
	Makaia Pedro	083 967 5408	mpedro@rems2.com
Approved by	Lenise van Laar	083 388 2131	lvanlaar@rems2.com
Manager	Andries Gous	083 419 8356	agous@rems2.com

Harmony Personnel

Designation	Name	Tel	Email
Environmental Manager: Free State Operations	John van Wyk	083 682 4089	jvwyk@harmony.co.za
Senior Environmental Officer: Water	Thigesh Vather	083 380 2531	Thigesh.Vather@Harmony.co.za
Surface: Environmental Officer	Ipeleng Sebetlele	079 546 1347	Ipeleng.Sebetlele@Harmony.co.za

www.mtbpower.com - Confidential document © MTB 2017

Water Uses according to NWA 36 of 1998

Section 21(a) of the Act: Taking water from a resource

ID	Source	Volume(m^3/a)
J_A1	Joel 3 South Shaft	3 060 000

Section 21(f) of the Act: Discharging waste or water containing waste into a water resource through a pipe, canal, sewer or other conduit

ID	Source	Volume(m^3/a)
J_F1	Joel Sewage Plant	1 095 000

Section 21(g) of the Act: Disposing waste or water in a manner which may detrimentally impact on a water resource

ID	Source	Volume(m^3/a)
J_G2	Joel Evaporation Dams	1 642 500
J_G3	Joel Stormwater Dam	572
J_G5	Joel 3 South Shaft TK1 Water Tank	1 422 180
J_G6	Joel Sewage Plant	365 240
J_G7	Joel 3 South (Taung South) Shaft Waste Rock Dump	45 042 tons
J_G8	Joel 1 North (Taung North) Shaft Waste Rock Dump	90 291 tons
J_G9	Joel Slime Dam Complex	168 000
J_G10	Joel Return Water Dam	14 730 000
J_G11	Dust suppression Joel 3 South (Taung South) Shaft Waste Rock Dump	6 570
J_G12	Dust suppression Joel 1 South (Taung North) Shaft Waste Rock Dump	6 570
J_G13	Dust suppression Joel Slime Dam Complex	6 570

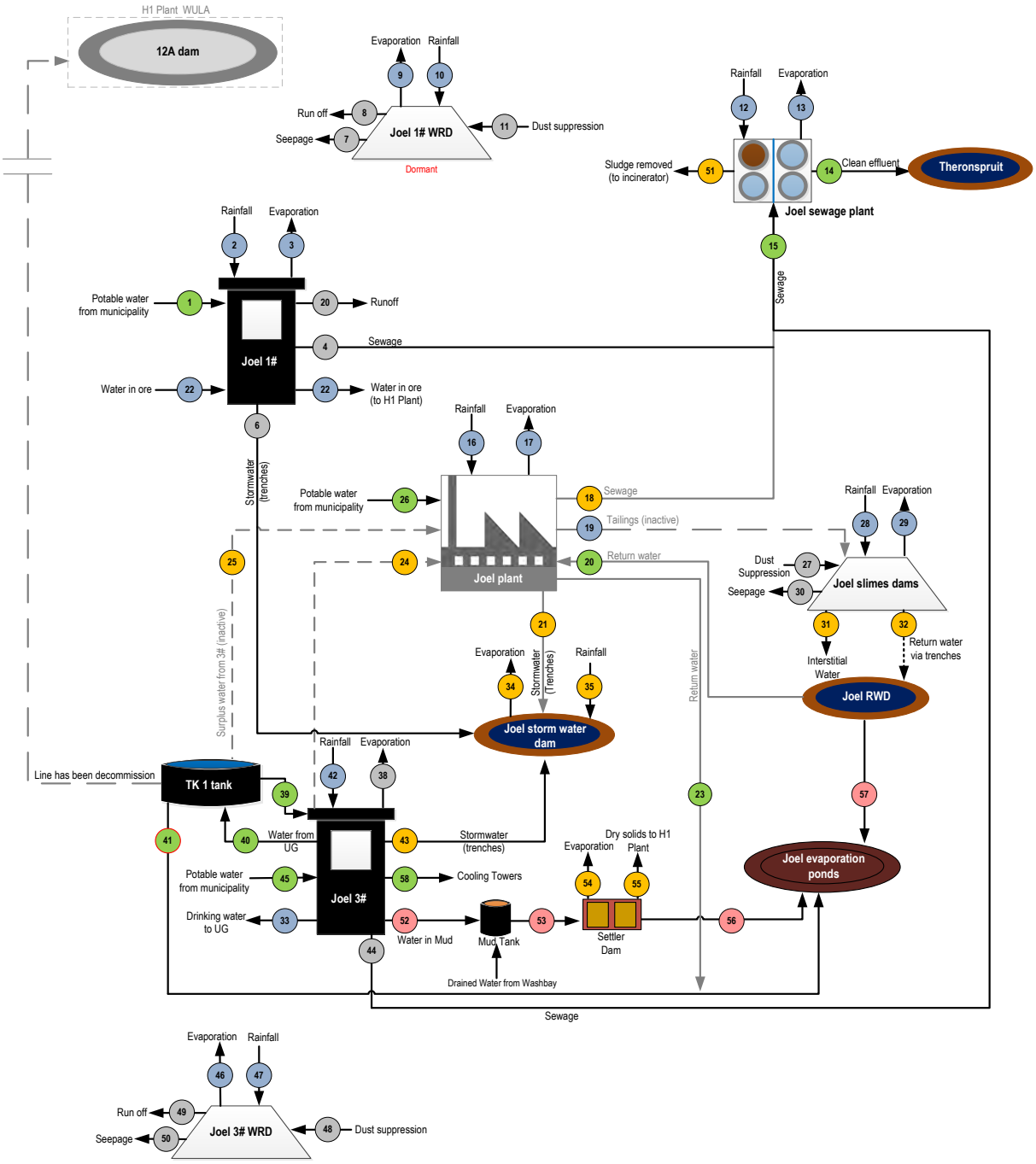
Section 21(j) of the Act: Removing, discharging or disposing of water found underground if it is necessary

ID	Source	Volume(m^3/a)
J_J1	Joel 3 South Shaft	3 060 000

*WULA values are based off of the 2020 application

www.mtbpower.com - Confidential document © MTB 2017

Joel Operations Layout

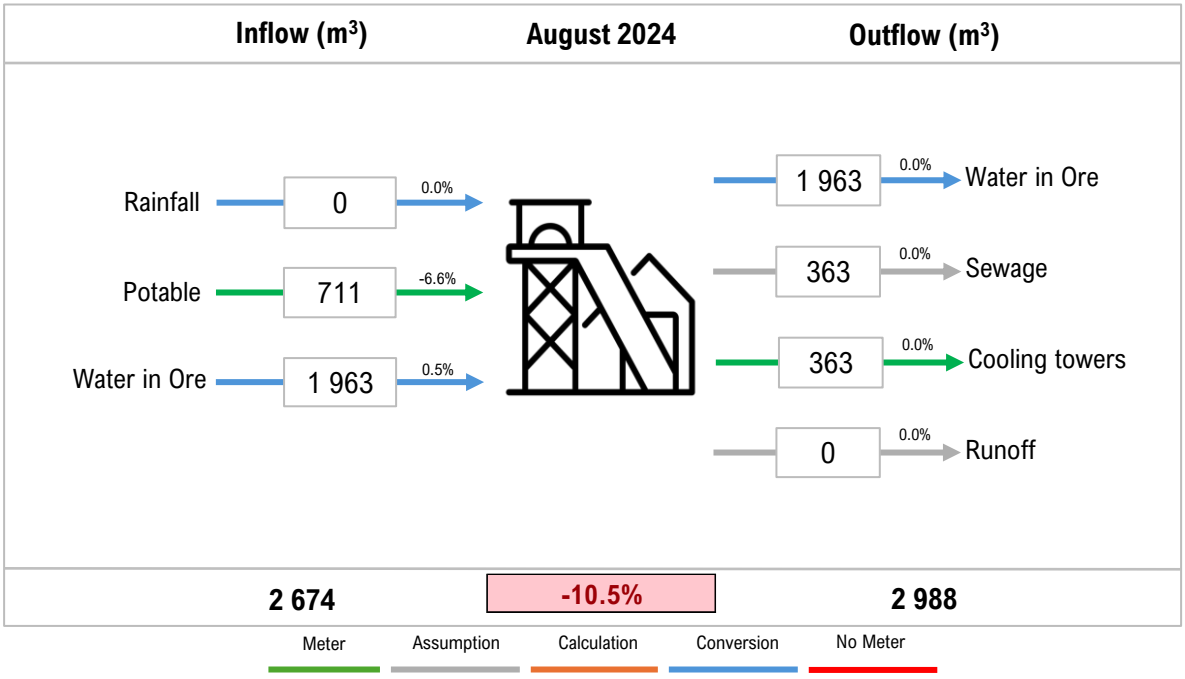


KEY METERS
Meter available
Conversion
Calculation
Meter not available
Faulty meter
Assumption

Document Title
Joel Operations Water Layouts
CONFIDENTIAL

www.mtbpower.com - Confidential document © MTB 2017

Joel 1 Shaft



Percentage indicates the change in volume from previous month

Inflows (m³)

Meter	Description	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24
1	**Potable Water**	980	838	882	754	761	711
2	**Rainfall**	991	10 012	0	0	0	0
22	**Water in Ore**	1 832	1 635	1 765	1 927	1 953	1 963
	Total Inflow	**3 803**	**12 484**	**2 647**	**2 681**	**2 714**	**2 674**

Outflows (m³)

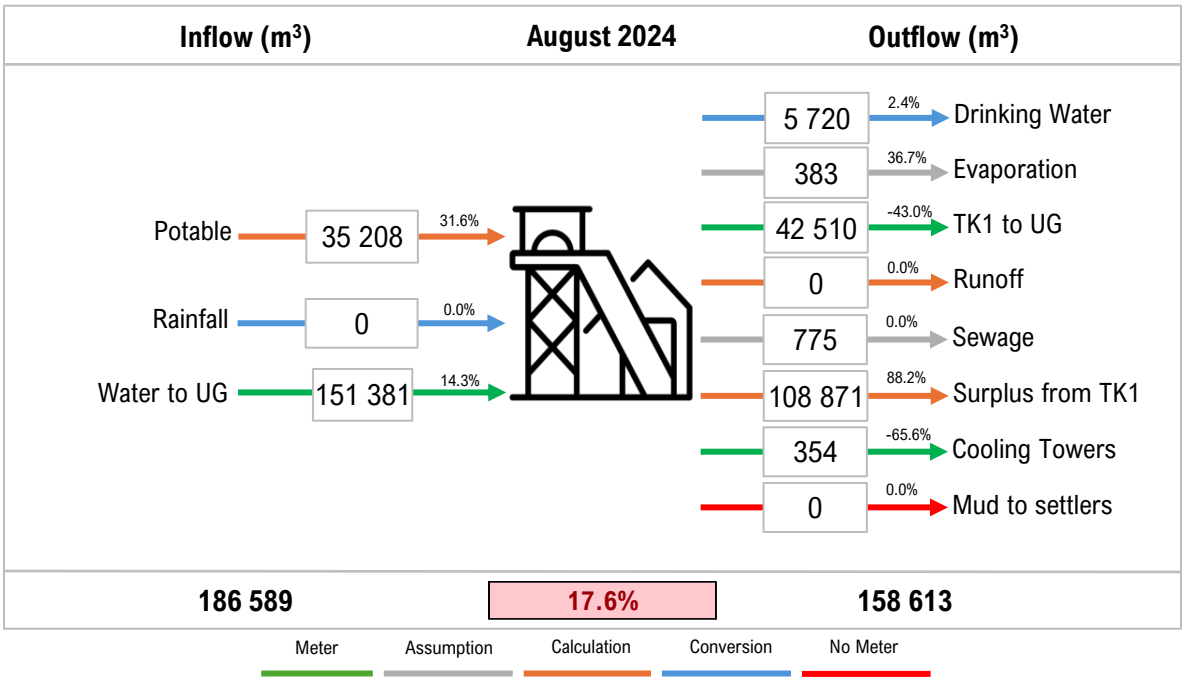
Meter	Description	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24
22	**Water in Ore**	1 832	1 635	1 765	1 927	1 953	1 963
20	**Runoff**	991	10 012	0	0	0	0
30	**Cooling towers**	1 075	694	644	1 723	621	662
4	**Sewage**	363	351	363	351	363	363
	Total Outflow	**4 260**	**12 691**	**2 771**	**4 001**	**2 937**	**2 988**

Variance	-10.7%	-1.6%	-4.5%	-33.0%	-7.6%	-10.5%

Comments

www.mtbpower.com - Confidential document © MTB 2017

Joel 3 Shaft



Percentage indicates the change in volume from previous month

Inflows (m³)

Meter	Description	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24
45	**Potable Water**	42 795	38 666	25 960	26 420	26 760	35 208
42	**Rainfall**	26	261	0	0	0	0
39	**TK1 to UG**	79 617	155 627	156 051	236 165	132 455	151 381
	Total Inflow	**122 438**	**194 554**	**182 011**	**262 585**	**159 215**	**186 589**

Outflows (m³)

Meter	Description	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24
33	**Drinking Water to UG**	4 389	4 038	5 641	5 417	5 585	5 720
38	**Evaporation**	521	394	309	247	280	383
40	**UG to TK1**	45 201	108 436	59 637	84 911	74 621	42 510
43	**Runoff**	26	261	0	0	0	0
44	**Sewage**	775	750	775	750	775	775
41	**Surplus Water from TK1**	34 416	47 191	96 414	151 254	57 834	108 871
58	**Cooling Towers**	12 976	8 492	161	1 489	1 028	354
52	**Mud to Settlers**	0	0	0	0	0	0
	Total Outflow	**98 304**	**169 563**	**162 937**	**244 068**	**140 123**	**158 613**

Variance	24.6%	14.7%	11.7%	7.6%	13.6%	17.6%

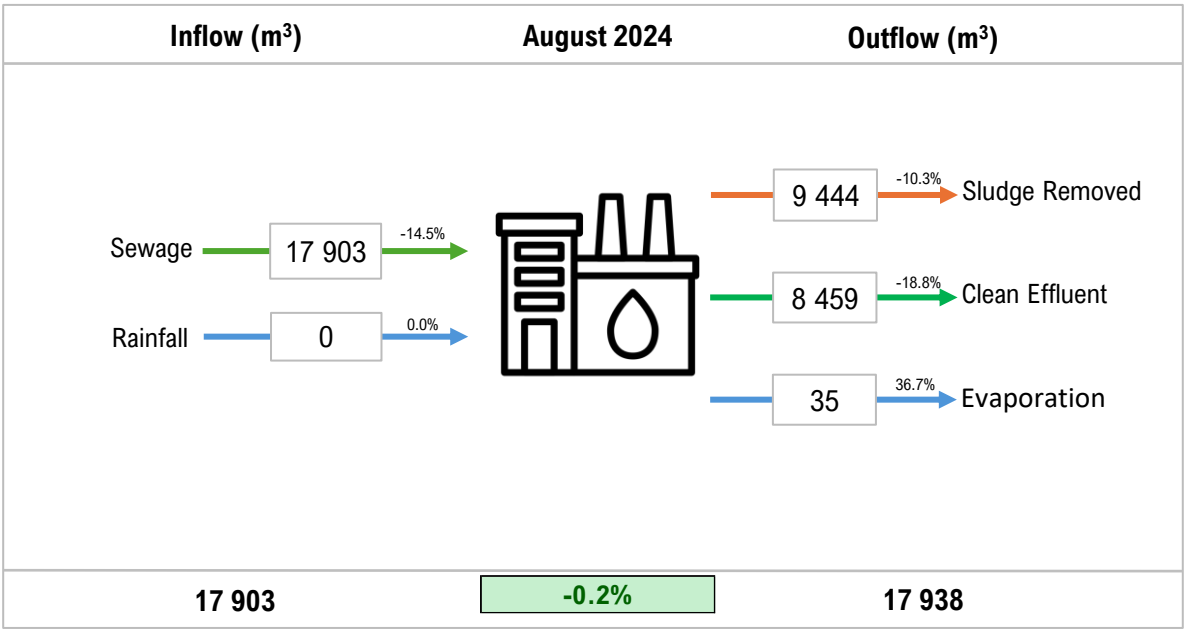
*Potable water calculated under current understanding of the potable water layout. Reservoir feeds to 1#, 3# and hostels. Thus calc used is 3# = reservoir - hostels - 1#

Comments

The imbalances at Joel 3# is being investigated and flow meters installed to improve the water balance and ensure all in and out flows are captured.

www.mtbpower.com - Confidential document © MTB 2017

Joel Sewage Plant



Percentage indicates the change in volume from previous month

Inflows (m^3)

Meter	Description	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24
15	**Sewage**	25 327	39 255	9 084	18 595	20 942	17 903
12	**Rainfall**	9	93	0	0	0	0
	Total Inflow	**25 336**	**39 348**	**9 084**	**18 595**	**20 942**	**17 903**

Outflows (m^3)

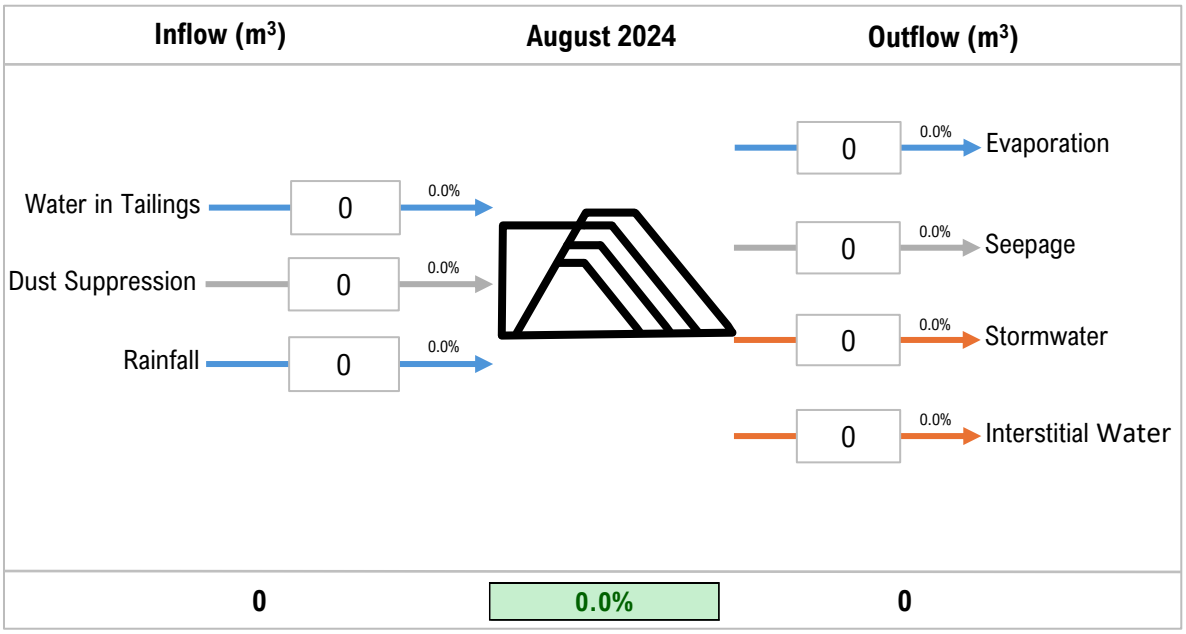
Meter	Description	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24
13	**Evaporation**	48	36	29	23	26	35
14	**Clean Effluent - Theronspruit**	6 042	16 289	9 069	6 034	10 418	8 459
51	**Sludge removed**	19 285	22 966	15	12 561	10 524	9 444
	Total Outflow	**25 375**	**39 291**	**9 113**	**18 618**	**20 968**	**17 938**

Variance	**-0.2%**	**0.1%**	**-0.3%**	**-0.1%**	**-0.1%**	**-0.2%**

Comments

www.mtbpower.com - Confidential document © MTB 2017

Joel TSF



Percentage indicates the change in volume from previous month

Inflows (m³)

Meter	Description	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24
19	**Water in Tailings from Plant**	0	0	0	0	0	0
27	**Dust Supression**	0	0	0	0	0	0
28	**Rainfall**	16 913	170 943	0	0	0	0
	Total Inflow	**16 913**	**170 943**	**0**	**0**	**0**	**0**

Outflows (m³)

Meter	Description	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24
29	**Evaporation**	0	0	0	0	0	0
30	**Seepage**	1 691	17 094	0	0	0	0
32	**Stormwater runoff to Joel RWD**	169	1 709	0	0	0	0
31	**Interstitial Water**	15 053	152 140	0	0	0	0
	Total Outflow	**16 913**	**170 943**	**0**	**0**	**0**	**0**

Variance	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

Comments

www.mtbpower.com - Confidential document © MTB 2017

Monthly volumes per water use (m^3)

Section 21(a)

WUL ID	Source	Purpose	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Total per annum	Applied volume
J_A1	Joel 3 South Shaft	Reuse of water removed from underground for the continuation of mining	106 898	94 078	130 928	120 580	221 805	86 844	79 617	155 627	156 051	236 165	132 455	151 381	**1 672 429**	3 060 000 m^3/a

Section 21(f)

WUL ID	Source	Purpose	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Total per annum	Applied volume
J_F1	Joel Sewage Plant	Discharge of treated sewage effluent into the Theronspruit	37 183	39 698	18 142	31 267	7 976	7 614	6 042	16 289	9 069	6 034	10 418	8 459	**198 191**	1 095 000 m^3/a

Section 21(f)

WUL ID	Source	Purpose	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Total per annum	Applied volume
J_G2	Joel Evaporation Dams	Excess water from the shafts and return water dam (emergency use only)	81 075	66 849	100 449	47 240	94 291	-	34 416	47 191	96 414	151 254	57 834	108 871	**885 884**	1 642 500 m^3/a
J_G3	Joel Stormwater Dam	Process water dam containing stormwater runoff	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	**NM**	572 m^3/a
J_G5	Joel 3 South Shaft TK1 Water Tank	Contains water abstracted from underground	106 898	94 078	130 928	120 580	221 805	86 844	79 617	155 627	156 051	236 165	132 455	151 381	**1 672 429**	1 422 180 m^3/a
J_G6	Joel Sewage Plant	Sewage treatment plant	37 183	39 698	18 142	31 267	7 976	7 614	6 042	16 289	9 069	6 034	10 418	8 459	**198 191**	365 240 m^3/a
J_G7	Joel 3 South (Taung South) Shaft WRD)	WRD (dormant)	0	0	0	0	0	0	0	0	0	0	0	0	**0**	45 042 tons
J_G8	Joel 1 North (Taung North) Shaft WRD	WRD (dormant)	0	0	0	0	0	0	0	0	0	0	0	0	**0**	90 291 m^3/a
J_G9	Joel Slime Dam Complex	TSF (dormant)	0	0	0	0	0	0	0	0	0	0	0	0	**0**	168 000 tons
J_G10	Joel Return Water Dam	Return Water Dam	0	0	0	0	0	0	0	0	0	0	0	0	**0**	14 730 000 tons

*Based on calculation due to meter unavailability.

www.mtbpower.com - Confidential document © MTB 2017

WUL ID	Source	Purpose	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Total per annum	Applied volume
J_G11	Dust suppression Joel 3 South (Taung South) Shaft WRD	Dust suppression using process water	0	0	0	0	0	0	0	0	0	0	0	0	**0**	6 570 m^3/a
J_G12	Dust suppression Joel 1 South (Taung North) Shaft WRD	Dust suppression using process water	0	0	0	0	0	0	0	0	0	0	0	0	**0**	6 570 m^3/a
J_G13	Dust suppression Joel Slime Dam Complex	Dust suppression using process water	0	0	0	0	0	0	0	0	0	0	0	0	**0**	6 570 m^3/a

Section 21(f)

WUL ID	Source	Purpose	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Total per annum	Applied volume
J_J1	Joel 3 South Shaft	Efficient continuation of underground workings	106 898	94 078	130 928	120 580	221 805	86 844	79 617	155 627	156 051	236 165	132 455	151 381	**1 672 429**	3 060 000 m^3/a

*WULA values are based off of the 2020 application

www.mtbpower.com - Confidential document © MTB 2017

Assumptions, Calculations and Conversions

Assumption	Description
Sewage	100L per person per day
Personnel on site per day - Joel 1 Shaft	117
Personnel on site per day - Joel 3 Shaft	1 851
Runoff at Plant/Shaft	Equal to Rainfall
Dust Supression	Volume per Annum/12
Runoff on Tailings	10% of Sector Area x Area Rainfall
Water in Ore	5% of Ore Weight

Abbreviations	Description
NM	Not Metered
RWD	Return Water Dam
STP	Sewage Treatment Plant
TSF	Tailings Storage Facility
WRD	Waste Rock Dump

www.mtbpower.com - Confidential document © MTB 2017

Assumptions, Calculations and Conversions

Evaporation rates

January	206.25 mm
February	162.96 mm
March	145.59 mm
April	110.13 mm
May	86.4 mm
June	69.02 mm
July	78.37 mm
August	107.14 mm
September	146.7 mm
October	183.63 mm
November	201.75 mm
December	212.65 mm

Evaporation values are based off of the 2020 WUL application

Surface areas (m^2)

Joel 1#	35 377	Joel TSF	798 237
Joel 3#	141 649	STP	604 040
TK1	924		

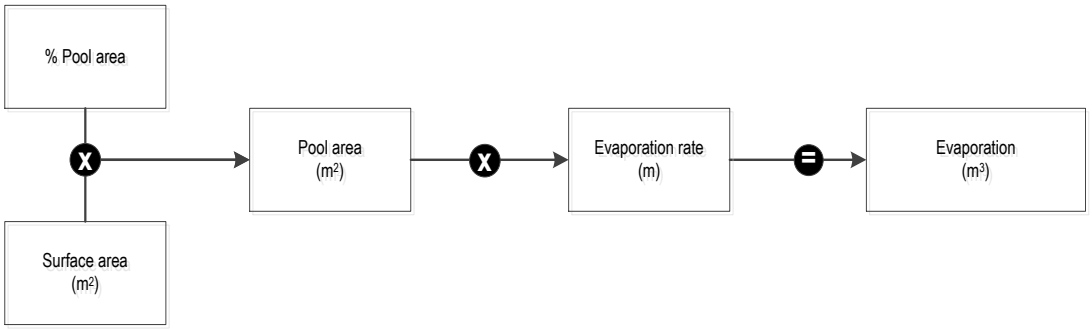
Google Earth estimations & Probabilistic water balance

% Pool area

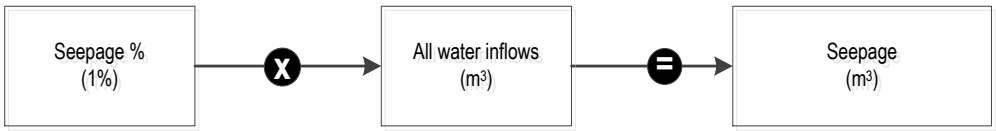
Shafts	0%
Waste rock dumps	5%
Slimes dams	10%
Open dams	100%

www.mtbpower.com - Confidential document © MTB 2017

Surface areas (m^2)



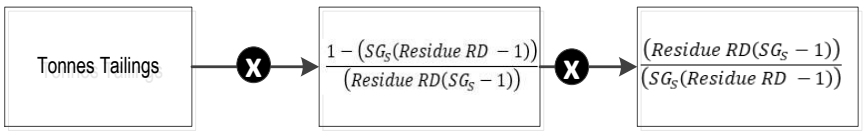
Seepage



Tailings properties

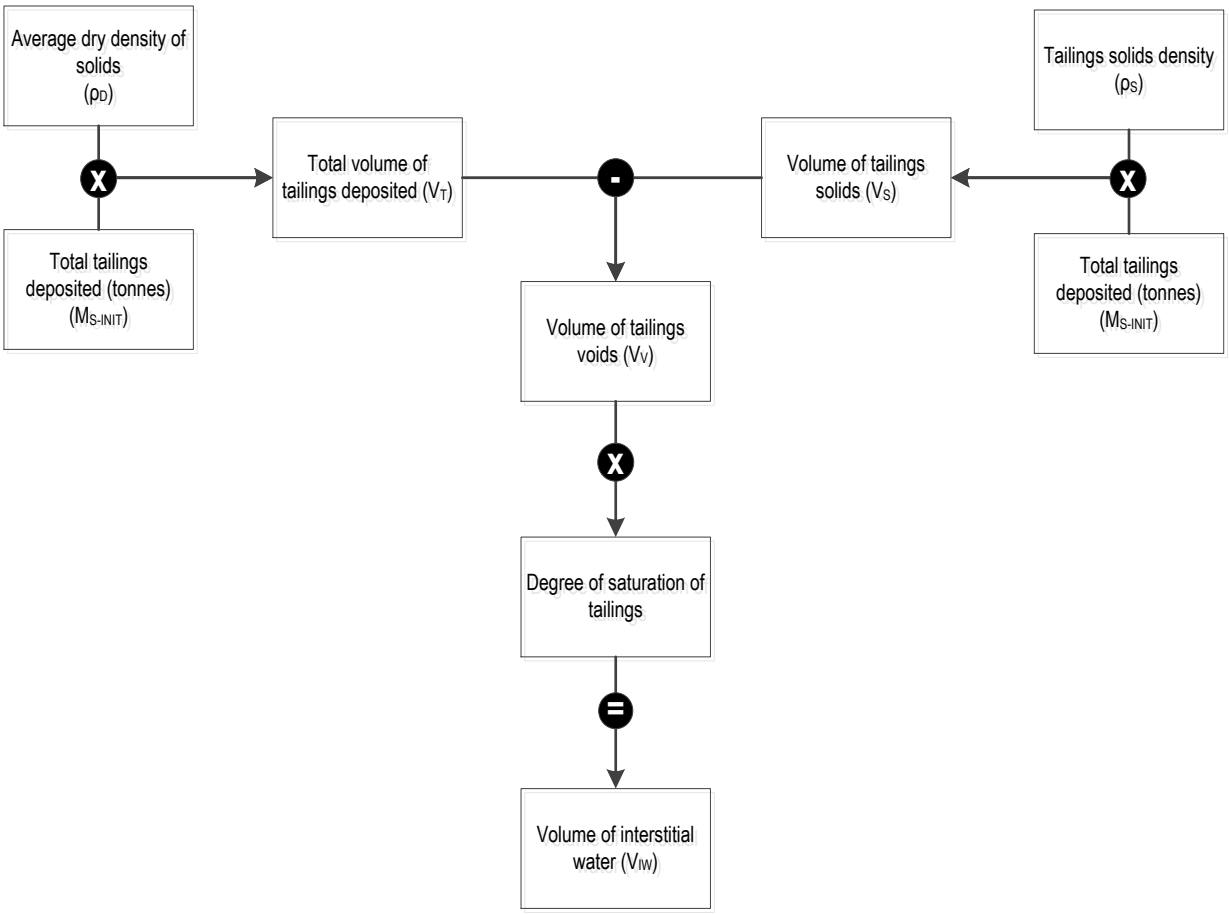
Degree of saturation	100%	Density of water	1 t/m³
SG of solids	2.63	Tailings average dry density	1.25 t/m³

Water in tailings



www.mtbpower.com - Confidential document © MTB 2017

Interstitial water



www.mtbpower.com - Confidential document © MTB 2017

Quantity Report:
Water Balance

Joel Operations

28 February 2025

Generated on 11 April 2025

Report verification

Document control

ETA Personnel

	Name	Tel	Email
Compiled by	**Danielle Greyvenstein**	072 374 0589	dgreyvenstein@rems2.com
Manager	**Lenise van Laar**	083 388 2131	lvanlaar@rems2.com
Contract Manager	**Andries Gous**	083 419 8356	agous@rems2.com

Harmony Personnel

Designation	Name	Tel	Email
Environmental Manager: Free State Operations	**John van Wyk**	083 682 4089	jvwyk@harmony.co.za
Senior Environmental Officer: Water	**Thigesh Vather**	083 380 2531	Thigesh.Vather@Harmony.co.za
Surface: Environmental Officer	**Ipeleng Sebetlele**	079 546 1347	Ipeleng.Sebetlele@Harmony.co.za

www.mtbpower.com - Confidential document © MTB 2017

Water Uses according to NWA 36 of 1998

Section 21(a) of the Act: Taking water from a resource

ID	Source	Volume(m^3/a)
J_A1	Joel 3 South Shaft	3 060 000

Section 21(f) of the Act: Discharging waste or water containing waste into a water resource through a pipe, canal, sewer or other conduit

ID	Source	Volume(m^3/a)
J_F1	Joel Sewage Plant	1 095 000

Section 21(g) of the Act: Disposing waste or water in a manner which may detrimentally impact on a water resource

ID	Source	Volume(m^3/a)
J_G2	Joel Evaporation Dams	1 642 500
J_G3	Joel Stormwater Dam	572
J_G5	Joel 3 South Shaft TK1 Water Tank	1 422 180
J_G6	Joel Sewage Plant	365 240
J_G7	Joel 3 South (Taung South) Shaft Waste Rock Dump	45 042 tons
J_G8	Joel 1 North (Taung North) Shaft Waste Rock Dump	90 291 tons
J_G9	Joel Slime Dam Complex	168 000
J_G10	Joel Return Water Dam	14 730 000
J_G11	Dust suppression Joel 3 South (Taung South) Shaft Waste Rock Dump	6 570
J_G12	Dust suppression Joel 1 South (Taung North) Shaft Waste Rock Dump	6 570
J_G13	Dust suppression Joel Slime Dam Complex	6 570

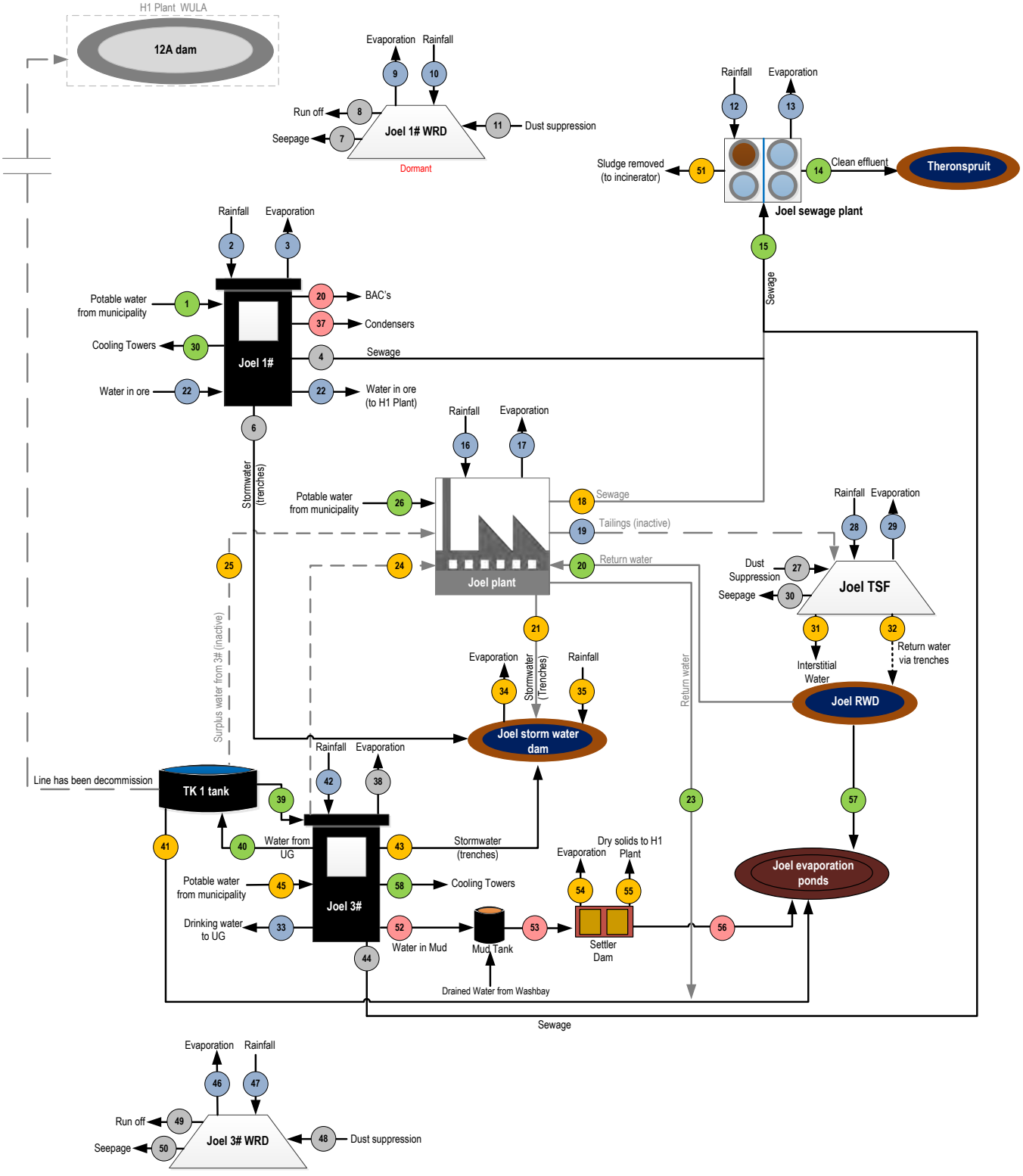
Section 21(j) of the Act: Removing, discharging or disposing of water found underground if it is necessary

ID	Source	Volume(m^3/a)
J_J1	Joel 3 South Shaft	3 060 000

*WULA values are based off of the 2020 application

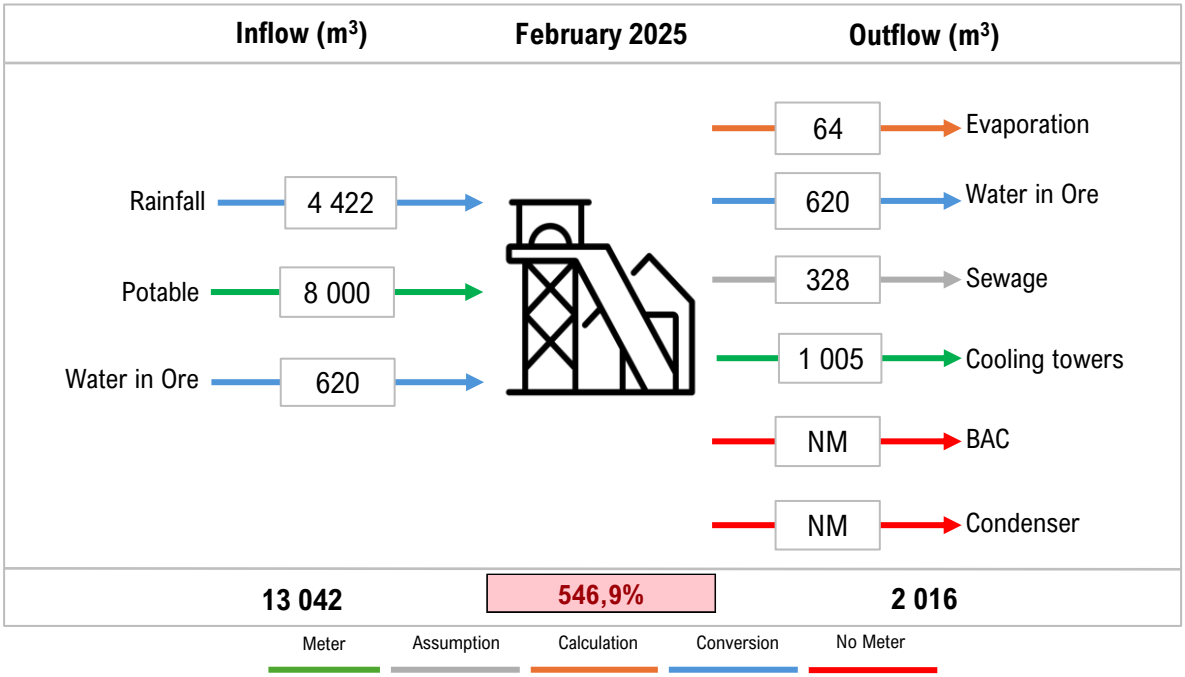
www.mtbpower.com - Confidential document © MTB 2017

Joel Operations Layout



KEY METERS	Document Title
Meter available	Joel Operations Water Layouts
Conversion	CONFIDENTIAL
Calculation	
Meter not available	
Faulty meter	
Assumption	

Joel 1 Shaft



Inflows (m³)

Meter	Description	Sept-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25
1	**Potable Water**	6 230	6 360	7 580	6 270	13 130	8 000
2	**Rainfall**	0	0	12	14	1 910	4 422
22	**Water in Ore**	1 886	1 373	1 638	963	476	620
	Total Inflow	**8 116**	**7 733**	**9 231**	**7 246**	**15 517**	**13 042**

Outflows (m³)

Meter	Description	Sept-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25
3	**Evaporation**	24	27	37	50	59	64
22	**Water in Ore**	1 886	1 373	1 638	963	476	620
30	**Cooling towers**	711	929	872	1 213	1 005	1 005
4	**Sewage**	351	363	351	363	363	328
20	**BAC's**	NM	NM	NM	NM	NM	NM
37	**Condenser**	NM	NM	NM	NM	NM	NM
	Total Outflow	**2 972**	**2 692**	**2 899**	**2 588**	**1 903**	**2 016**

Variance	**173,1%**	**187,3%**	**218,4%**	**179,9%**	**715,5%**	**546,9%**

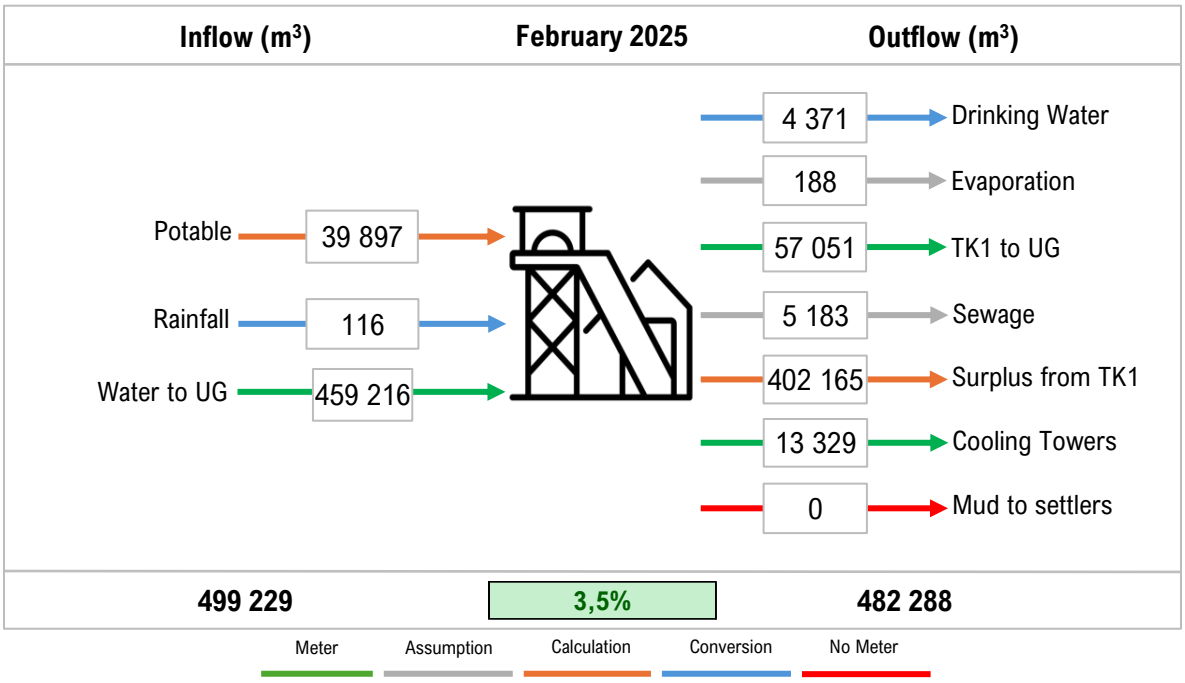
Requested for flow meters to be installed at the BAC and Condenser - 21 November 2024.

Cooling Towers meter broken 29 January 2025, average used in Jan and Feb

Comments

www.mtbpower.com - Confidential document © MTB 2017

Joel 3 Shaft



Inflows (m³)

Meter	Description	Sept-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25
45	**Potable Water**	47 538	58 592	45 045	32 342	54 500	39 897
42	**Rainfall**	0	0	37	41	50	116
39	**TK1 to UG**	171 162	203 474	186 703	120 851	209 858	459 216
	Total Inflow	**218 700**	**262 066**	**231 785**	**153 234**	**264 408**	**499 229**

Outflows (m³)

Meter	Description	Sept-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25
33	**Drinking Water to UG**	5 810	7 428	6 422	4 263	2 429	4 371
38	**Evaporation**	71	81	111	149	175	188
40	**UG to TK1**	68 423	72 192	34 965	31 167	30 613	57 051
44	**Sewage**	5 553	5 738	5 553	5 738	5 738	5 183
41	**Surplus Water from TK1**	102 739	131 282	151 738	89 684	179 245	402 165
58	**Cooling Towers**	28 979	16 983	19 129	12 517	13 140	13 329
52	**Mud to Settlers**	0	0	0	0	0	0
	Total Outflow	**211 575**	**233 704**	**217 918**	**143 518**	**231 340**	**482 288**

Variance	**3,4%**	**12,1%**	**6,4%**	**6,8%**	**14,3%**	**3,5%**

*Potable water calculated under current understanding of the potable water layout. Reservoir feeds to 1#, 3# and hostels. Thus calculation used is 3# = reservoir - hostels - 1#

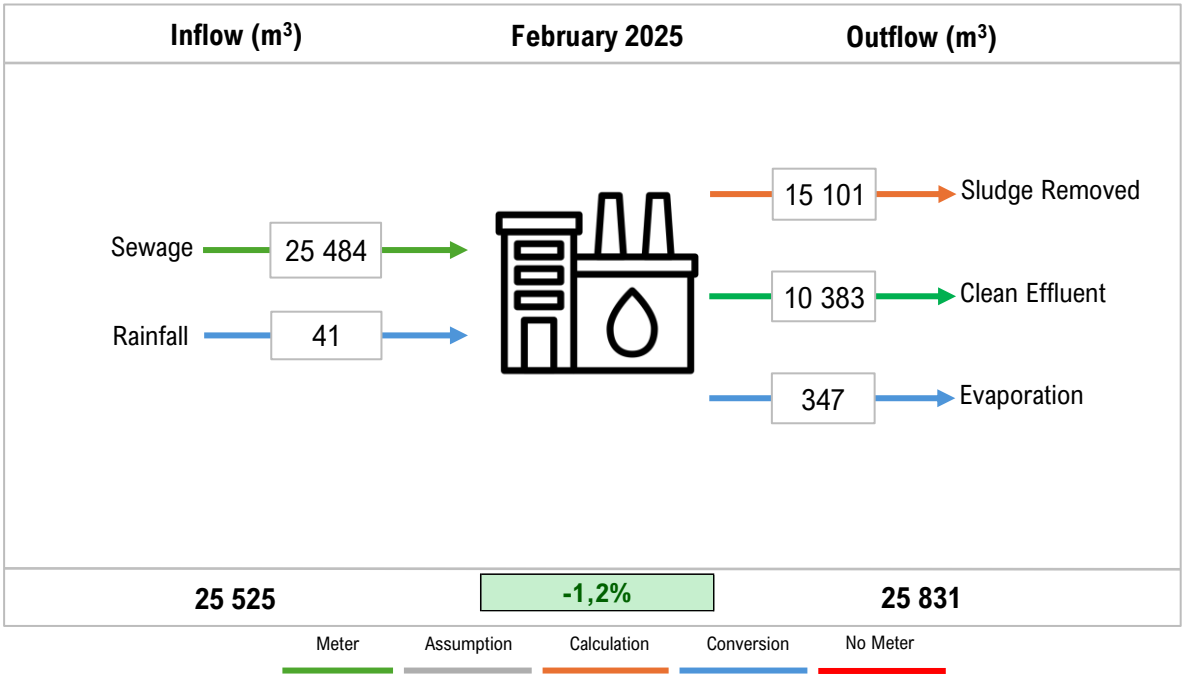
*Requested for flow meter to be fixed - 21 November 2024

*Average due to drinking water meter broken - 05 February 2025

Comments

www.mtbpower.com - Confidential document © MTB 2017

Joel Sewage Plant



Inflows (m³)

Meter	Description	Sept-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25
15	**Sewage**	17 900	23 162	27 093	22 401	24 803	25 484
12	**Rainfall**	0	0	68	75	18	41
	Total Inflow	**17 900**	**23 162**	**27 161**	**22 476**	**24 821**	**25 525**

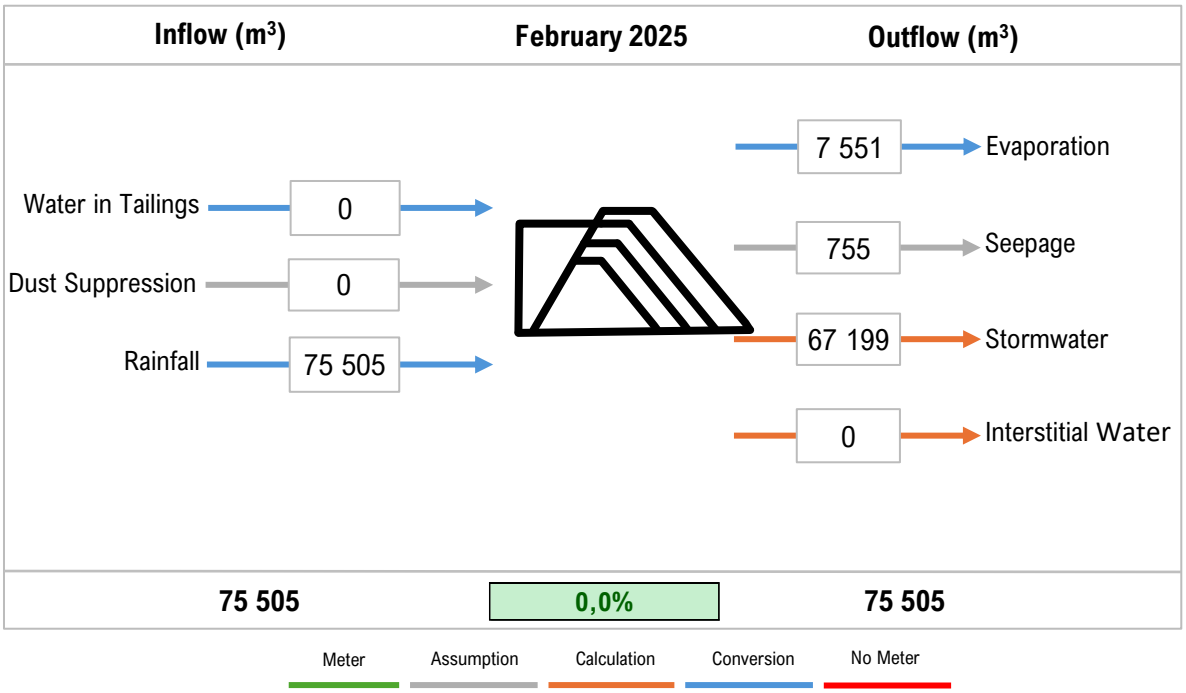
Outflows (m³)

Meter	Description	Sept-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25
13	**Evaporation**	131	150	204	274	322	347
14	**Clean Effluent - Theronspruit**	10 686	8 581	21 410	10 293	9 126	10 383
51	**Sludge removed**	7 214	14 581	5 683	12 108	15 677	15 101
	Total Outflow	**18 031**	**23 312**	**27 297**	**22 675**	**25 125**	**25 831**
Variance		**-0,7%**	**-0,6%**	**-0,5%**	**-0,9%**	**-1,2%**	**-1,2%**

Comments

www.mtbpower.com - Confidential document © MTB 2017

Joel TSF



Inflows (m³)

Meter	Description	Sept-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25
19	**Water in Tailings from Plant**	0	0	0	0	0	0
27	**Dust Suppression**	0	0	0	0	0	0
28	**Rainfall**	0	0	24 162	26 578	32 618	75 505
	Total Inflow	**0**	**0**	**24 162**	**26 578**	**32 618**	**75 505**

Outflows (m³)

Meter	Description	Sept-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25
29	**Evaporation**	0	0	2 416	2 658	3 262	7 551
30	**Seepage**	0	0	242	266	326	755
32	**Stormwater runoff to Joel RWD**	0	0	21 504	23 654	29 030	67 199
31	**Interstitial Water**	0	0	0	0	0	0
	Total Outflow	**0**	**0**	**24 162**	**26 578**	**32 618**	**75 505**

Variance	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%

Comments

Assumptions, Calculations and Conversions

Assumption	Description
Sewage	100L per person per day
Personnel on site per day - Joel 1 Shaft	117
Personnel on site per day - Joel 3 Shaft	1 851
Runoff at Plant/Shaft	Equal to Rainfall
Dust Suppression	Volume per Annum/12
Runoff on Tailings	10% of Sector Area x Area Rainfall
Water in Ore	Calculated based on moisture factor

Abbreviations	Description
NM	Not Metered
RWD	Return Water Dam
STP	Sewage Treatment Plant
TSF	Tailings Storage Facility
WRD	Waste Rock Dump

www.mtbpower.com - Confidential document © MTB 2017

Assumptions, Calculations and Conversions

Evaporation rates

January	189 mm	July	119 mm
February	204 mm	August	101 mm
March	225 mm	September	77 mm
April	215 mm	October	88 mm
May	171 mm	November	120 mm
June	159 mm	December	161 mm

Evaporation values are based off of the 2020 WUL application

Surface areas (m^2)

Joel 1#	35 377	**Joel TSF**	798 237
Joel 3#	141 649	**STP**	604 040
TK1	924		

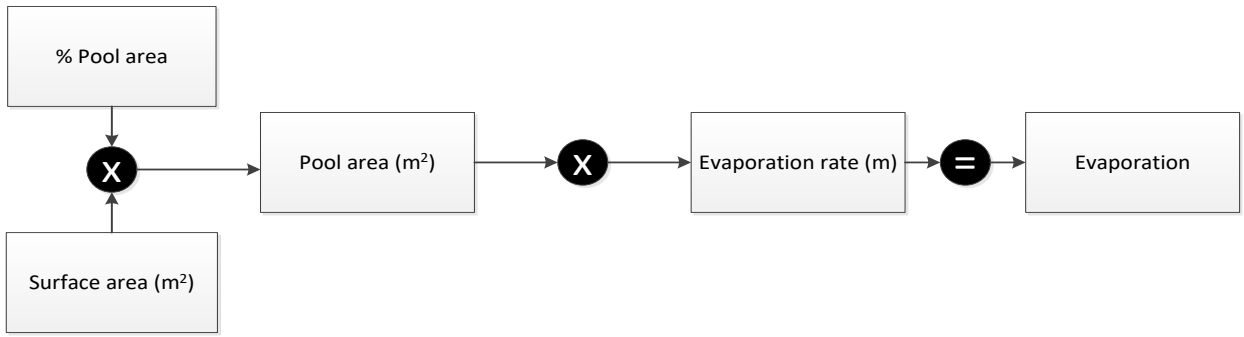
Google Earth estimations & Probabilistic water balance

% Pool area

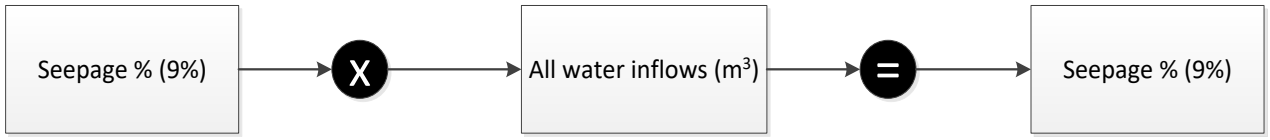
Shafts	0%
Waste rock dumps	5%
Slime dams	10%
Open dams	100%

www.mtbpower.com - Confidential document © MTB 2017

Evaporation (m^2)



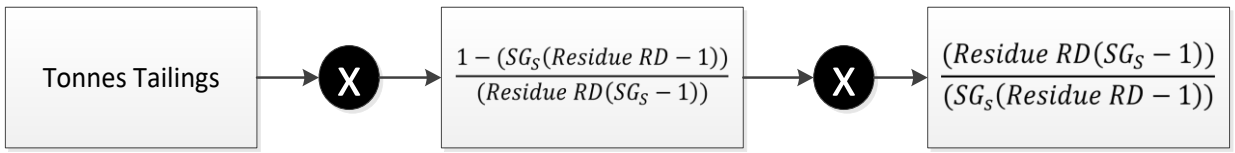
Seepage



Tailings properties

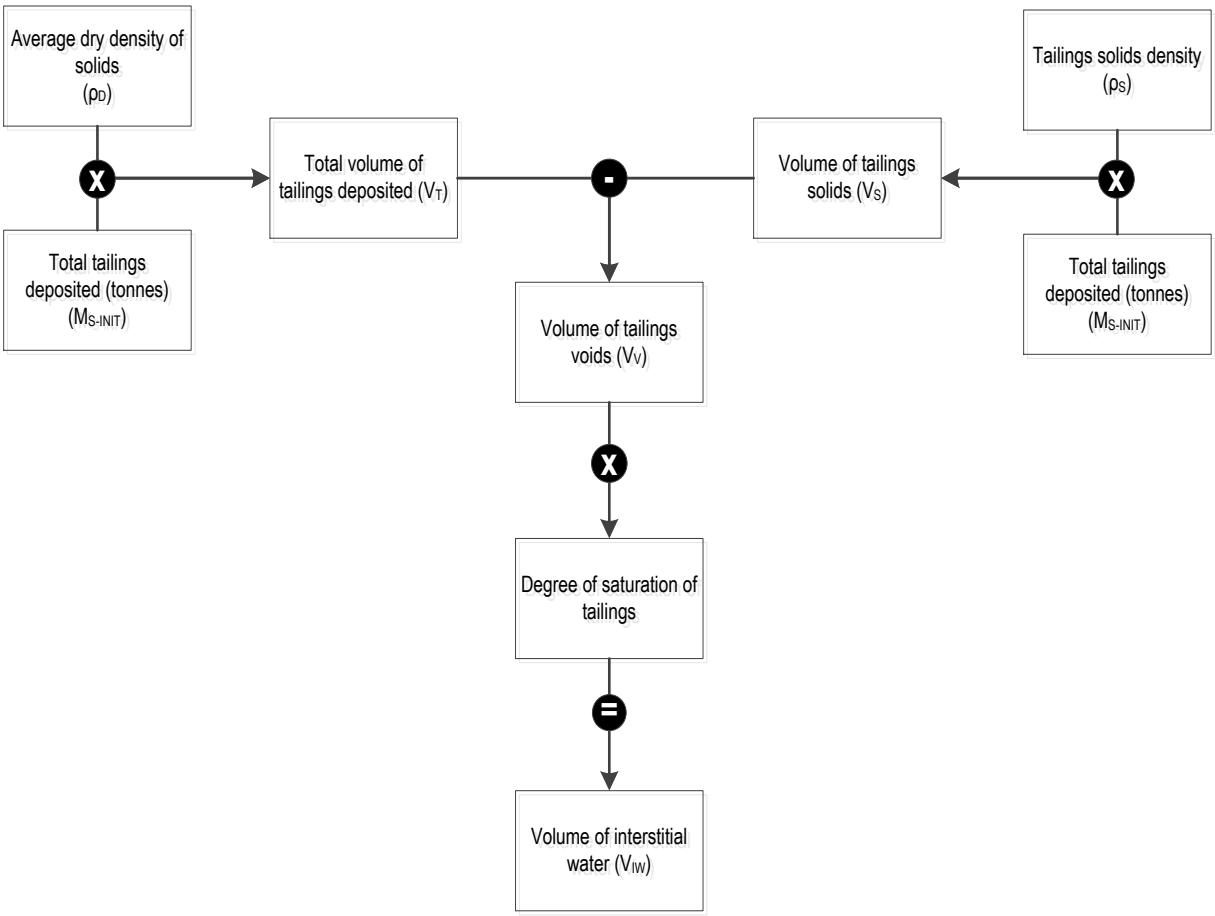
Degree of Saturation	100%	**Density of water**	1 t/m^3
SG of solids	2.63	**Tailings average dry density**	1.25 t/m^3

Water in tailings



www.mtbpower.com - Confidential document © MTB 2017

Interstitial water



www.mtbpower.com - Confidential document © MTB 2017

Appendix D: Surface Water Study

Surface Water Study for the Harmony Gold Mining Free State Operations NWA Section 21 (c) and (i) Water Uses Project

Project Number:

KON024

Prepared for:

Kongiwe Environmental (Pty) Ltd

150 Bryanston Drive, Bryanston, Sandton, 2191, South Africa

Email: info@kongiwe.com

Tel: +27 (10) 140 6508

Fax: 083 476 6438

Compiled by:

Hydrospatial (Pty) Ltd

17 Sonop Place, Randpark, Johannesburg, 2194

Email: andy@hydrospatial.co.za

Tel: +27 84 441 9539

October 2023

DOCUMENT CONTROL

Project Name	Surface Water Study for the Harmony Gold Mining Free State Operations NWA Section 21 (c) and (i) Water Uses Project
Report Type	Hydrological Study
Client	Kongiwe Environmental (Pty) Ltd
Project Number	KON024
Report Number	02
Report Status	Draft
Submission Date	13 October 2023
Author	Andy Pirie (Hydrologist, M.Sc., *Pr.Sci.Nat.114988*)
Author Signature	

DISCLAIMER

The opinions, results and findings expressed in this report, are based on the authors best scientific knowledge, as well as on the information supplied to Hydrospatial as part of the project. The accuracy of the results and conclusions in this report, are reliant on the accuracy and completeness of the supplied information. Hydrospatial does not accept responsibility for any errors or omissions in the supplied information, and does not accept any consequential liability arising from commercial decisions or actions resulting from them.

TABLE OF CONTENTS

1 INTRODUCTION AND BACKGROUND 1

1.1 Project Location 1

1.2 Project Description 1

1.2.1 Life of Operation 2

1.3 Legal Requirements and Guidelines 2

1.4 Details of the Specialist 4

2 SCOPE OF WORK 4

3 BASELINE HYDROLOGY 4

3.1 Climate 4

3.1.1 Rainfall 4

3.1.2 Evaporation 6

3.2 Hydrological Setting 6

3.2.1 Regional Catchments and Drainage 6

3.2.2 Topography 8

3.2.3 Land Cover/Use 8

3.2.4 Geology and Soils 11

4 METHODOLOGY 11

4.1 Site Investigations 11

4.2 Floodline Determination 11

4.2.1 Elevation Data 11

4.2.2 Peak Flows 11

4.2.2.1 Rational Method 11

4.2.2.2 Empirical Deterministic Peak Discharge Method (Midgley and Pitman) 12

4.2.2.3 SCS Method 13

4.2.3 Software 13

4.2.4 Hydraulic Model Setup 14

4.2.5 Assumptions and Limitations 14

4.2.6 Manning's Roughness Coefficients 14

4.3 GN R704 Audit 16

4.3.1 Assumptions and Limitations 16

4.4 Conceptual Stormwater Management Plan 17

5 JOEL OPERATIONS 17

5.1 Description of Operations 17

5.2 Floodlines 20

5.3 GN R704 Audit 20

5.4 Conceptual Stormwater Management Plan 25
5.4.1 Existing Stormwater Measures 25
5.4.1.1 South Shaft 25
5.4.1.2 North Shaft 27
5.4.1.3 Other Areas 27
5.4.2 Clean and Dirty Areas 27
5.4.3 Proposed Stormwater Measures and Recommendations 27

6 SAAIPLAAS OPERATIONS 28

6.1 Description of Operations 28
6.2 Floodlines 31
6.3 GN R704 Audit 31
6.4 Conceptual Stormwater Management Plan 37
6.4.1 Existing Stormwater Measures 37
6.4.1.1 Saaiplaas Plant 37
6.4.1.2 Brand A Slimes Dam Complex 37
6.4.1.3 No. 21/H3 Slimes Dam 40
6.4.1.4 St Helena 1, 2, 3 Slimes Dam Complex 40
6.4.1.5 Other Slimes Dams 40
6.4.1.6 Waste Rock Dumps 40
6.4.2 Clean and Dirty Areas 41
6.4.3 Proposed Stormwater Measures and Recommendations 41

7 TARGET OPERATIONS 42

7.1 Description of Operations 42
7.2 Floodlines 45
7.3 GN R704 Audit 45
7.4 Conceptual Stormwater Management Plan 54
7.4.1 Existing Stormwater Measures 54
7.4.1.1 Target Plant 54
7.4.1.2 Target 1 Shaft 54
7.4.1.3 Waste Rock Dumps 54
7.4.1.4 Slimes Dams 58
7.4.1.5 Other Areas 58
7.4.2 Clean and Dirty Areas 58
7.4.3 Proposed Stormwater Measures and Recommendations 58
7.4.3.1 Target Plant 58
7.4.3.2 Target 1 Shaft 58
7.4.3.3 Waste Rock Dumps 59
7.4.3.4 Other Areas 59

8 CENTRAL OPERATIONS 59

8.1 Description of Operations 59

8.2 Floodlines 62
8.3 GN R704 Audit 62
8.4 Conceptual Stormwater Management Plan 67
8.4.1 Existing Stormwater Measures 67
8.4.1.1 Central Plant 67
8.4.1.2 Waste Rock Dumps 67
8.4.1.3 Slimes Dams 67
8.4.2 Clean and Dirty Areas 67
8.4.3 Proposed Stormwater Measures and Recommendations 70
8.4.3.1 Central Plant 70
8.4.3.2 Waste Rock Dumps 70
8.4.3.3 Slimes Dams 70
9 HARMONY 1 OPERATIONS 70
9.1 Description of Operations 70
9.2 Floodlines 74
9.3 GN R704 Audit 74
9.4 Conceptual Stormwater Management Plan 91
9.4.1 Existing Stormwater Measures 91
9.4.1.1 Harmony 1 Plant 91
9.4.1.2 Tshepong Shaft 91
9.4.1.3 Phakisa Shaft 92
9.4.1.4 Nyala Shaft 92
9.4.1.5 Eland Shaft 92
9.4.1.6 Masimong 4 Shaft 102
9.4.1.7 Masimong 5 Shaft 102
9.4.1.8 Slimes Dams 102
9.4.1.9 Waste Rock Dumps 102
9.4.2 Clean and Dirty Areas 102
9.4.3 Proposed Stormwater Measures and Recommendations 103
9.4.3.1 Harmony 1 Plant 103
9.4.3.2 Tshepong Shaft 103
9.4.3.3 Phakisa Shaft 103
9.4.3.4 Nyala Shaft 103
9.4.3.5 Eland Shaft 104
9.4.3.6 Masimong 4 Shaft 104
9.4.3.7 Masimong 5 Shaft 104
9.4.3.8 Other Areas 104
10 REFERENCES 105
APPENDIX A: GN R704 REGULATIONS 107
APPENDIX B: CURRICULUM VITAE 108

LIST OF TABLES

Table 3-1: Storm rainfall depths for the area 5

Table 3-2: Monthly and annual evaporation at the Harmony Free State Operations 6

Table 3-3: Harmony Free State Operations quaternary catchments 7

Table 3-4: Harmony Free State Operations Land Cover 8

Table 4-1: Selected Manning's roughness coefficients for the rivers flowing through the Harmony Operations 14

Table 5-1: Summary of activities undertaken at the Joel Operation 17

Table 5-2: Peak flows used to determine the floodlines for the Saaiplaas Operations 20

Table 5-3: Joel Operations GN R704 non-compliances and recommendations 22

Table 6-1: Summary of activities undertaken at the Saaiplaas Operations 28

Table 6-2: Peak flows used to determine the floodlines for the Saaiplaas Operations 31

Table 6-3: Saaiplaas Operations GN R704 non-compliances and recommendations 34

Table 7-1: Summary of activities undertaken at the Target Operation 42

Table 7-2: Peak flows used to determine the floodlines for the Target Operations 45

Table 7-3: Target Operations GN R704 non-compliances and recommendations 49

Table 8-1: Summary of activities undertaken at the Central Operations 60

Table 8-2: Peak flows used to determine the floodlines for the Central Operations 62

Table 8-3: Central Operations GN R704 non-compliances and recommendations 65

Table 9-1: Summary of activities undertaken at the Harmony 1 Operations 71

Table 9-2: Peak flows used to determine the floodlines for the Harmony 1 Operations 74

Table 9-3: Harmony 1 Operations GN R704 non-compliances and recommendations 84

LIST OF FIGURES

Figure 1-1: Location of the project 3

Figure 3-1: Topographical Map 9

Figure 3-2: Land cover map 10

Figure 5-1: Joel Operations and floodlines 19

Figure 5-2: Location of the GN R704 non-compliances at the Joel Operations..... 21
Figure 5-3: Conceptual stormwater management plan for the Joel Operations 26
Figure 6-1: Saaiplaas Operations and floodlines 30
Figure 6-2: Location of the GN R704 non-compliances at the Saaiplaas Operations (east). 32
Figure 6-3: Location of the GN R704 non-compliances at the Saaiplaas Operations (west) 33
Figure 6-4: Conceptual stormwater management plan for the Saaiplaas Operations (east) 38
Figure 6-5: Conceptual stormwater management plan for the Saaiplaas Operations (west) 39
Figure 7-1: Target Operations and floodlines 44
Figure 7-2: Location of the GN R704 non-compliances at the Target Operations (south).... 46
Figure 7-3: Location of the GN R704 non-compliances at the Target Operations (north) 47
Figure 7-4: Location of the GN R704 non-compliances at the Target Plant and 1 Shaft..... 48
Figure 7-5: Conceptual stormwater management plan for the Target Operations (south).... 55
Figure 7-6: Conceptual stormwater management plan for the Target Operations (north) 56
Figure 7-7: Conceptual stormwater management plan for the Target Plant and 1 Shaft..... 57
Figure 8-1: Central Operations and floodlines 61
Figure 8-2: Location of the GN R704 non-compliances at the Central Operations..... 63
Figure 8-3: Location of the GN R704 non-compliances at the Central Operations Plant..... 64
Figure 8-4: Conceptual stormwater management plan for the Central Operations 68
Figure 8-5: Conceptual stormwater management plan for the Central Operations Plant 69
Figure 9-1: Harmony 1 Operations and floodlines 73
Figure 9-2: Location of the GN R704 non-compliances at the Harmony 1 Plant..... 75
Figure 9-3: Location of the GN R704 non-compliances at the Tshepong Shaft 76
Figure 9-4: Location of the GN R704 non-compliances at the Phakisa Shaft 77
Figure 9-5: Location of the GN R704 non-compliances at the FSN Slimes Dams and surrounding infrastructure 78
Figure 9-6: Location of the GN R704 non-compliances at the ARM Slimes Dam and surrounding infrastructure 79
Figure 9-7: Location of the GN R704 non-compliances at the Masimong 4 Shaft..... 80

Figure 9-8: Location of the GN R704 non-compliances at the Masimong 5 Shaft 81

Figure 9-9: Location of the GN R704 non-compliances at the FSS Slimes Dams and surrounding infrastructure 82

Figure 9-10: Location of the GN R704 non-compliances at the southern waste rock dumps 83

Figure 9-11: Conceptual stormwater management plan for the Harmony 1 Plant 93

Figure 9-12: Conceptual stormwater management plan for the Tshepong Shaft 94

Figure 9-13: Conceptual stormwater management plan for the Phakisa Shaft 95

Figure 9-14: Conceptual stormwater management plan for the Nyala Shaft 96

Figure 9-15: Conceptual stormwater management plan for the FSN Slimes Dams and surrounding infrastructure 97

Figure 9-16: Conceptual stormwater management plan for the ARM Slimes Dam and surrounding infrastructure 98

Figure 9-17: Conceptual stormwater management plan for the Masimong 4 Shaft 99

Figure 9-18: Conceptual stormwater management plan for the Masimong 5 Shaft 100

Figure 9-19: Conceptual stormwater management plan for the southern waste rock dumps 101

DECLARATION OF INDEPENDENCE

I, Andy Pirie declare that:

- I act as the independent specialist in this application;
- I will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant;
- I declare that there are no circumstances that may compromise my objectivity in performing such work;
- I have the expertise in conducting the specialist study relevant to this application, including knowledge of the various Acts, regulations and any guidelines that have relevance to the proposed project;
- I will comply with the Acts, regulations and all other applicable legislation;
- I have no, and will not engage in, conflicting interests in the undertaking of the activity;
- I undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing any decision to be taken with respect to the application by the competent authority; and the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority;
- All the particulars furnished by me in this form are true and correct; and
- I realise that a false declaration is an offence in terms of regulation 71 and is punishable in terms of Section 24F of the National Environmental Management Act.



Andy Pirie
Senior Hydrologist
Pr.Sci.Nat (reg no. 114988)

ACRONYMS AND ABBREVIATIONS

BPG	Best Practice Guideline
CV	Curriculum Vitae
DEM	Digital Elevation Model
DTM	Digital Terrain Model
DWA	Department of Water Affairs (now the DWS)
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EIA	Environmental Impact Assessment
ELUs	Existing lawful water uses
GIS	Geographical Information System
GN R704	Government Notice No. R704
GPS	Global Positioning System
IWULA	Integrated Water Use Licence Application
km	Kilometres
LDM	Lejweleputswa District Municipality
m	Metres
MAR	Mean Annual Runoff
mamsl	metres above mean sea level
MERRA-2	Modern-Era Retrospective analysis for Research and Applications, Version 2
MPRDA	Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002)
NASA	National Aeronautics and Space Administration
NEMA	National Environmental Management Act, 1998 (Act No. 107 of 1998)
NWA	National Water Act, 1998 (Act No. 36 of 1998)
Pr.Sci.Nat.	Professional Natural Scientist
RWD	Return Water Dam
SCS	Soil Conservation Service
SACNASP	South African Council for Natural Scientific Professions
SANRAL	South African National Road Agency Limited
SWMP	Stormwater Management Plan
Tc	Time of concentration
TSF	Tailings Storage Facility
WR2012	Water Resources of South Africa, 2012 Study
WUL	Water Use Licence
WULA	Water Use Licence Application
WMAs	Water Management Areas
WRC	Water Research Commission

TERMINOLOGY

Activity: Any mining related process on the mine including the operation of washing plants, mineral processing facilities, mineral refineries and extraction plants; the operation and the use of mineral loading and off-loading zones, transport facilities and mineral storage yards, whether situated at the mine or not; in which any substance is stockpiled, stored, accumulated, dumped, disposed of or transported;

Clean area: This refers to any unpolluted area at or near a mine or activity, which has the potential to become contaminated by mining activities if not managed appropriately;

Clean water system: This includes any dam, other form of impoundment, canal, works, pipeline and any other structure or facility constructed for the retention or conveyance of clean unpolluted water;

Dam: This includes any return water dam, settling dam, tailings dam, evaporation dam, catchment or barrier dam and any other form of impoundment used for the storage of unpolluted water or water containing waste;

Dirty area: This refers to any area at a mine or activity which causes, has caused or is likely to cause pollution of a water resource (i.e. generate contaminated water as a result of mining activities);

Dirty water system: This includes any dam, other form of impoundment, canal, works, pipeline, residue deposit and any other structure or facility constructed for the retention or conveyance of water containing waste; and

Watercourse: A watercourse is defined in the National Water Act, 1998 (Act 36 of 1998) as –

- A river or spring;
- A natural channel in which water flows regularly or intermittently;
- A wetland, lake or dam into which, or from which, water flows; and
- Any collection of water which the Minister may, by notice in the *Gazette,* declare to be a watercourse, and a reference to a watercourse includes, where relevant, its bed and banks.

1 INTRODUCTION AND BACKGROUND

Hydrospatial (Pty) Ltd was appointed by Kongiwe Environmental (Pty) Ltd to conduct a surface water hydrological study for the Harmony Gold Mining Free State Operations ("Harmony Free State Operations") Section 21 (c) and (i) Water Uses Project (hereafter referred to as the "project"). This report provides the surface water study for the Water Use Licence Application (WULA) process.

1.1 Project Location

The Harmony Free State Operations, owned by Harmony Gold Mining Company Limited ("Harmony"), are located within the Lejweleputswa District Municipality (LDM) in the Free State Province. These operations consist of five processing plants and numerous shafts that are either operational, under care and maintenance or decommissioned. The location of the five operations is shown on Figure 1-1 and include:

- Central Operations – located approximately 14 km south-east of Welkom and 5 km north of Virginia;
- Harmony 1 Operations – located approximately 6 km north-east of Welkom, 4 km south of Odendaalsrus and 8 km north-east of Virginia;
- Joel Operations – located 15 km south-west of Virginia and 20 km north-east of Theunissen;
- Saaiplaas Operations – located approximately 5 km south-east of Welkom, 8 km north-west of Virginia and 8 km south-east of Riebeeckstad; and
- Target Operations – located approximately 7 km north of Odendaalsrus, 3 km south of Allanridge and 26 km east of Wesselsbron.

1.2 Project Description

The Harmony Free State Operations have been mining the Vaal Reefs since the 1950s. The operations fall within the Vaal River Catchment area. The surface water drainage across the Harmony Free State Operations is mainly from the south-east towards the northwest.

Water/exemption permits for various water uses associated with Harmony Free State Operations were issued by the Department of Water and Sanitation (DWS) (then the Department of Water Affairs and Forestry (DWAF)), under the old Water Act (Act 54 of 1956). An Integrated Water Use Licence Application (IWULA), under the National Water Act (Act No. 36 of 1998) (NWA), was submitted by Harmony to the DWS (then called the Department of Water Affairs (DWA) at the time) in 2009. However, due to various reasons, the 2009 IWULA was not progressed.

Following this, five new IWULAs were submitted by Harmony for Section 21 water uses (excluding Section 21 (c) and (i) waters uses) in October 2020, which are currently being processed by the DWS. As part of those 2020 IWULA processes, Harmony also committed to

submitting separate IWULAs for the remaining Section 21 (c) and (i) activities. It is noted that the majority of the 21 (c) and (i) activities now being applied for are Existing Lawful Uses (ELUs). ELUs, in terms of Section 32 of the NWA, apply to water uses that physically took place in the two years preceding the promulgation of the NWA (from 1 October 1996 to 30 September 1998 for groundwater and 1 October 1997 to 30 September 1999 for surface water) and had been lawful in terms of previous legislation (that is, the old Water Act, Act 54 of 1956).

Therefore, the purpose of these five new IWULAs is to license existing infrastructure in line with the current regulatory framework in terms of the NWA (i.e., water uses in terms of Section 21 (c) and (i)).

1.2.1 Life of Operation

Mining was initiated during the 1950s (other than Target, which commenced in 2002), and processing operations began in 1986. The approximate remaining life of the current Harmony Free State operations is approximately 20 years, until at least 2040, however, many of the activities at the operations will end before then.

1.3 Legal Requirements and Guidelines

The following key legislative requirements and guidelines are relevant to this study:

- National Water Act, 1998 (Act No. 36 of 1998) (NWA);
- Regulations on the Use of Water for Mining and Related Activities aimed at the Protection of Water Resources (published under Government Notice 704 (GN R704) in Government Gazette 20119, 4 June 1999). A copy of GN R704 is provided in Appendix A;
- National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA) and associated Environmental Impact Assessment (EIA) 2014 regulations;
- Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002) (MPRDA); and
- Department of Water and Sanitation (DWS) Best Practice Guideline (BPG) documents, particularly:
    - BPG G1: Storm Water Management; and
    - BPG A5: Water Management for Surface Mines.

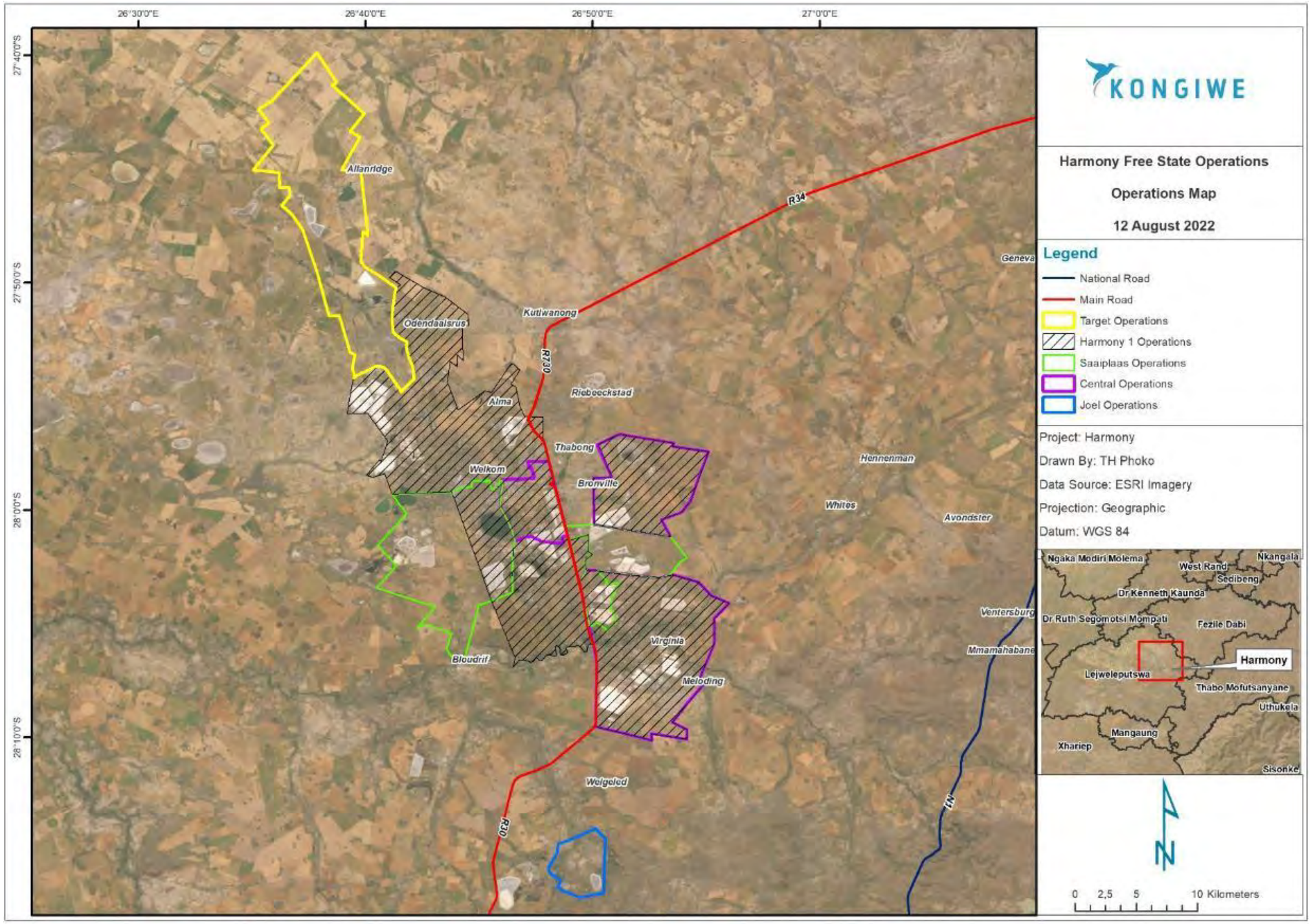


Figure 1-1: Location of the project

1.4 Details of the Specialist

The study was undertaken by Andy Pirie who is a senior hydrologist at Hydrospatial (Pty) Ltd. Andy graduated with a Master of Science (M.Sc.) in Water Resource Management (cum laude). He is registered as a Professional Natural Scientist (Pr.Sci.Nat) (registration number: 114988) in Water Resources Science with the South African Council for Natural Scientific Professions (SACNASP). Work experience includes rainfall – runoff modelling, floodline determinations, stormwater management plans, water and salt balance modelling, setup of water monitoring networks and programmes, analysis of surface water quality and quantity, and surface water specialist studies for environmental impact assessments and WULAs. He has worked on mining and construction projects in South Africa, Cameroon, Senegal, Mali, Democratic Republic of the Congo, Botswana, Zambia and Namibia. His curriculum vitae is provided in Appendix B.

2 SCOPE OF WORK

The scope of work included the following:

- Description of the baseline (current) hydrology;
- Determination of the 1:50 and 1:100 year floodlines and 100 m river buffers. According to GN R704[1] regulations, no mine infrastructure should be developed within the floodlines or within a 100 m horizontal distance of a watercourse, unless exemption from GN R704 is obtained from the DWS;
- GN R704 audit to determine areas that are non-compliant and to provide recommendations for improvement to achieve compliance; and
- Development of a conceptual Stormwater Management Plan (SWMP) in accordance with the DWS Best Practice Guideline G1: Storm Water Management and GN R704 regulations. The primary purpose of the SWMP is to ensure that clean (non-impacted water) and dirty water (mine impacted water) are separated and managed in accordance with the above-mentioned guideline and regulations;

3 BASELINE HYDROLOGY

3.1 Climate

3.1.1 Rainfall

Rainfall data from 1980 to 2016 was sourced from the National Aeronautics and Space Administration's (NASA) Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) dataset. The possibility of wet days in Welkom varies notably throughout the year. The mean monthly rainfall is indicated in Figure 3-1. Rainfall is highest in the months of October to April, and lowest over May to September. February has the most rainy days, while July has the fewest rainy days. The rainfall data was obtained for the periods of 1980 to 2016.

[1] Regulations on Use of Water for Mining and Related Activities Aimed at the Protection of Water Resources; 4 June 1999

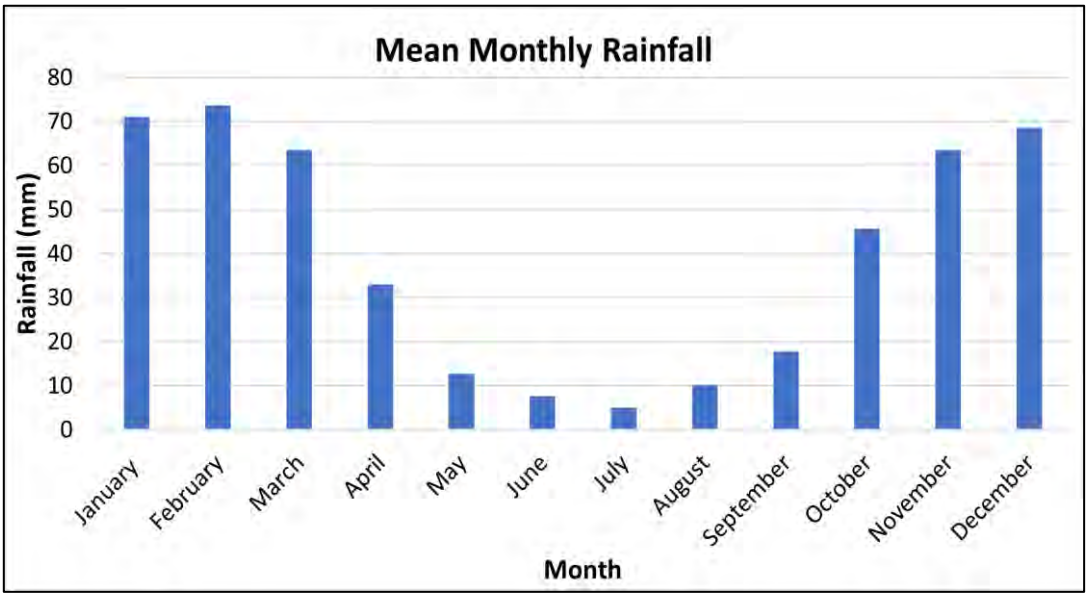


Figure 3-1: Mean monthly rainfall for the area

The storm rainfall depths in the vicinity of Welkom were extracted from the Design Rainfall Estimation in South Africa software programme (Smithers and Schulze, 2002). The programme uses the six closest rainfall stations to a user specified position to calculate the storm rainfall depths. The extracted storm rainfall depths for the project are indicated in Table 3-1.

Table 3-1: Storm rainfall depths for the area

Storm Duration	Storm Rainfall Depth (mm)						
	1:2 yr	1:5 yr	1:10 yr	1:20 yr	1:50 yr	1:100 yr	1:200 yr
5 min	9	13	15	17	20	23	25
10 min	14	19	22	25	30	33	37
15 min	17	24	28	32	38	42	47
30 min	22	30	35	41	48	53	59
45 min	25	34	40	46	55	61	68
1 hr	28	38	45	51	60	68	75
1.5 hr	32	43	51	59	69	78	86
2 hr	35	48	56	65	76	85	95
4 hr	41	56	66	76	89	100	111
6 hr	45	61	72	83	98	109	121
8 hr	48	65	77	89	104	117	129
10 hr	51	68	81	93	110	123	136
12 hr	53	71	84	97	114	128	142
16 hr	56	76	90	103	122	136	151
20 hr	59	80	94	109	128	143	159
24 hr	62	83	98	113	133	149	165
1 day	51	69	82	94	111	124	138
2 day	63	85	101	116	136	153	169
3 day	71	96	114	131	154	172	191
4 day	77	104	123	142	167	187	207
5 day	82	111	131	151	178	199	220

Storm Duration	Storm Rainfall Depth (mm)						
	1:2 yr	1:5 yr	1:10 yr	1:20 yr	1:50 yr	1:100 yr	1:200 yr
6 day	87	117	138	159	187	209	232
7 day	90	122	144	166	196	219	242

3.1.2 Evaporation

Evaporation data from 2000 - 2012 was sourced from the DWS hydrological dataset. The average evaporation based on the data is provided in Table 3-2 (Jones & Wagener, 2017).

Table 3-2: Monthly and annual evaporation at the Harmony Free State Operations

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average	189	204	225	215	171	159	119	101	77	88	120	161	1869
Minimum	92	99	105	100	95	93	82	76	63	57	64	59	997
Maximum	247	274	315	298	218	218	144	138	97	121	150	234	2197

3.2 Hydrological Setting

3.2.1 Regional Catchments and Drainage

The DWS has divided South Africa into primary, secondary, tertiary and quaternary catchments. Primary catchments are the largest defined catchments for South Africa, of which there are 22, and are assigned a letter ranging from A – X (excluding O). Secondary catchments are subdivisions of the primary catchments, and are the second largest catchments in South Africa, and are assigned the primary catchment letter within which they are located, and a number e.g. A5 (secondary catchment 5 located within primary catchment A). Similarly, tertiary catchments are subdivisions of secondary catchments, and are represented for example by A53 (tertiary catchment 3 located within secondary catchment A5). Lastly, quaternary catchments are the smallest defined catchments and are assigned the tertiary catchment number, along with a quaternary catchment letter e.g. A53D (quaternary catchment D located within tertiary catchment A53).

Further to the above, the DWS has divided South Africa into 9 Water Management Areas (WMAs). The 9 WMAs comprise the Limpopo, Olifants, Inkomati-Usuthu, Pongola-Mtamvuna, Vaal, Orange, Mzimvubu-Tsitsikamma, Breede-Gouritz and Berg-Olifants.

The project is located within the Vaal WMA, and within several quaternary catchments as per Table 3-3 below.

Table 3-3: Harmony Free State Operations quaternary catchments

Operation	Quaternary Catchments
Central Operation	C42J and C42H
Harmony One Operation	C25B, C43B, C42J, C42K and C42H
Joel Operation	C42K
Saaiplaas Operation	C43B, C42J and C42K
Target Operation	C25B

The surface water drainage across the Harmony Free State Operations is mainly from the southeast towards the northwest.

The Sand River runs through the middle of the Central Operation. The Rietspruit (a tributary of the Sand River) is situated to the east and the Merriespruit is situated to the south-west of the Central Operation. The Rietspruit originates within the vicinity of the Central Operation area, and surface runoff generated from the north of the Rietspruit is directed from the north-east towards the south-west. The Rietspruit has its confluence with the Sand River downstream of the Central Operation. The Merriespruit originates approximately 10 km to the east-north-east of the Central Operation. Surface runoff generated from the northeast is directed towards the southwest to the Merriespruit. This spruit flows into the Sand River.

The Sand River is situated to the south, the Rietspruit (a tributary of the Sand River) is situated to the south-east, the Sandspruit is situated to the north-east and the Mahemspruit is situated to the west of the Harmony One Operation. The Sand River is the largest drainage feature in the Harmony One Operation area, and originates approximately 120 km south-east from the operation, in the Senekal District.

The Doring River runs from the north to the north-east of the Joel Operation. The Doring River originates from the south of the Joel Operations and water from this river flows into the Sand River located approximately 19 km to the north-west of the operations. Surface runoff generated at the Joel operations is directed from the south-east towards the north-west to the river.

The Sand River is situated to the south and the Rietspruit (a tributary of the Sand River) is situated to the south-east of the Saaiplaas Operation. Surface runoff generated from the north of the Rietspruit is directed from the north-east towards the south-west to the river. The Rietspruit has its confluence with the Sand River approximately 4.5 km downstream of the Saaiplaas Operation.

The Sandspruit is situated to the east of the Target Operation. The Sandspruit originates within the vicinity of the Target Operation and flows from the south-east towards the north-east. Surface runoff mainly generated from the Phakisa and Tshepong shafts is directed to the Sandspruit.

3.2.2 Topography

According to the terrain morphological division, the area is described as pans and plains (Shangoni, 2009). Figure 3-1 shows the topography of the project area. Elevation in the project area varies from 1 300 metres above mean sea level (mamsl) along the northern side of the Harmony Free State Operations, to 1400 mamsl in the south-eastern sections of the operations. The Central Operation has the highest elevation while the Target Operation has the lowest elevation amongst all five operations.

3.2.3 Land Cover/Use

Land cover data was sourced from the Department of Environmental Affairs (DEA) (now the Department of Forestry, Fisheries and the Environment (DFFE)). Table 3-4 provides a summary of the land cover of the project area.

Table 3-4: Harmony Free State Operations Land Cover

Operation	Land Cover
Central Operation	Commercial annual crops rain-fed / dryland, natural grassland, residential formal (low veg / grass), natural pans, mine: tailings and resource dumps, herbaceous wetlands, and industrial
Harmony One Operation	Commercial annual crops rain-fed / dryland, natural grassland, residential formal (low veg / grass), natural pans, mine: tailings and resource dumps, herbaceous wetlands, industrial, open & sparse plantation forest, mines: extraction pits, and quarries, mines: surface infrastructure
Joel Operation	Mine: tailings and resource dumps, mines: surface infrastructure, natural grassland, fallow land and old fields (grass), open woodland, herbaceous wetlands
Saaiplaas Operation	Natural pans, open & sparse plantation forest, mines: extraction pits, quarries, mines: surface infrastructure, urban recreational fields (grass), commercial annual crops pivot irrigated, industrial, residential formal (low veg / grass)
Target Operation	Commercial annual crops rain-fed/dryland, natural grassland, natural pans, village dense (brae and low veg/grass combo), herbaceous wetlands, and mine: tailings and resource dumps

Most of the land cover within the Harmony Free State Operations is classified as mine tailings and resource dumps, commercial annual crops, natural grassland and formal residential areas. Figure 3-2 illustrates land cover in the project area.

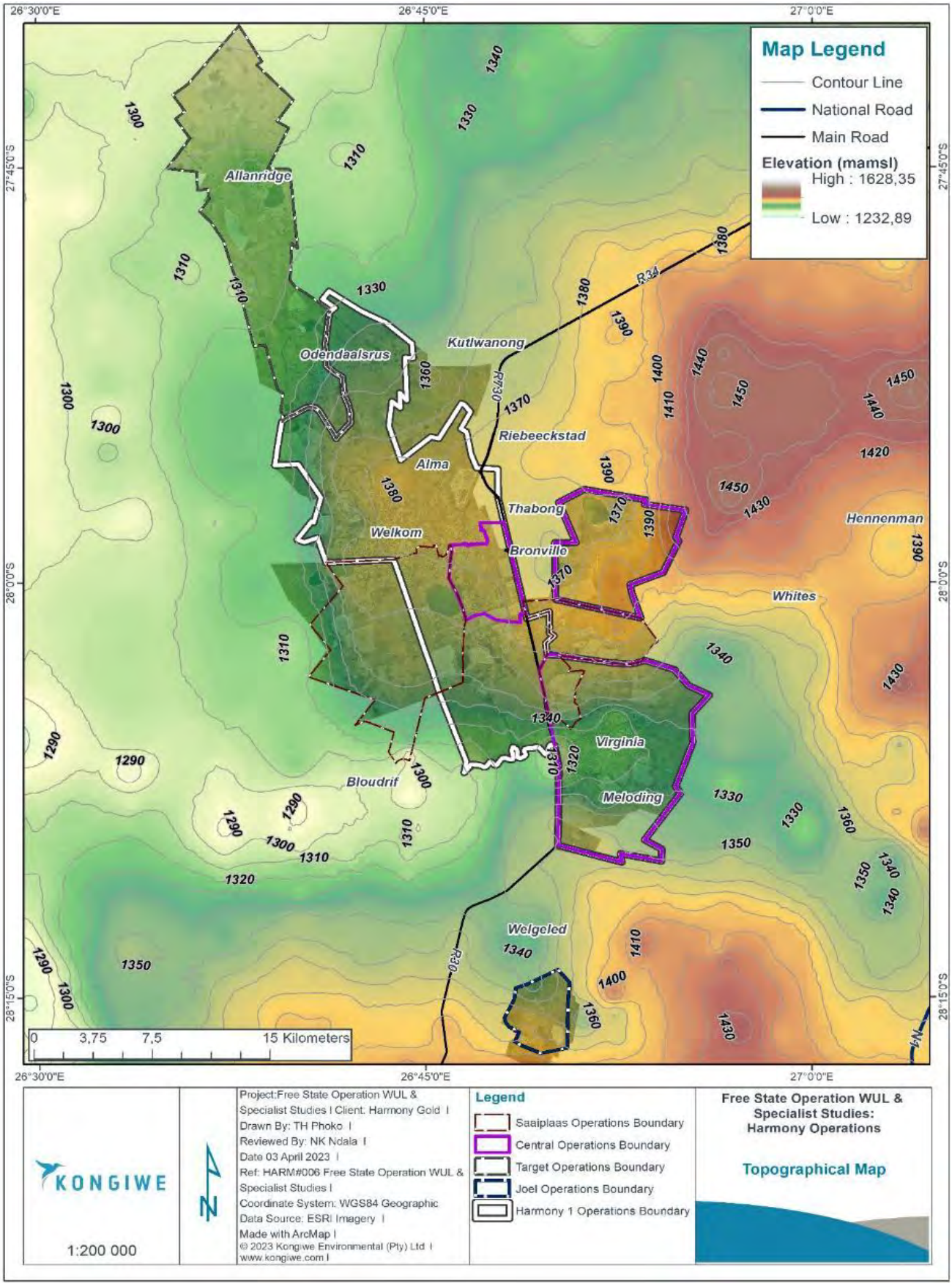


Figure 3-1: Topographical Map

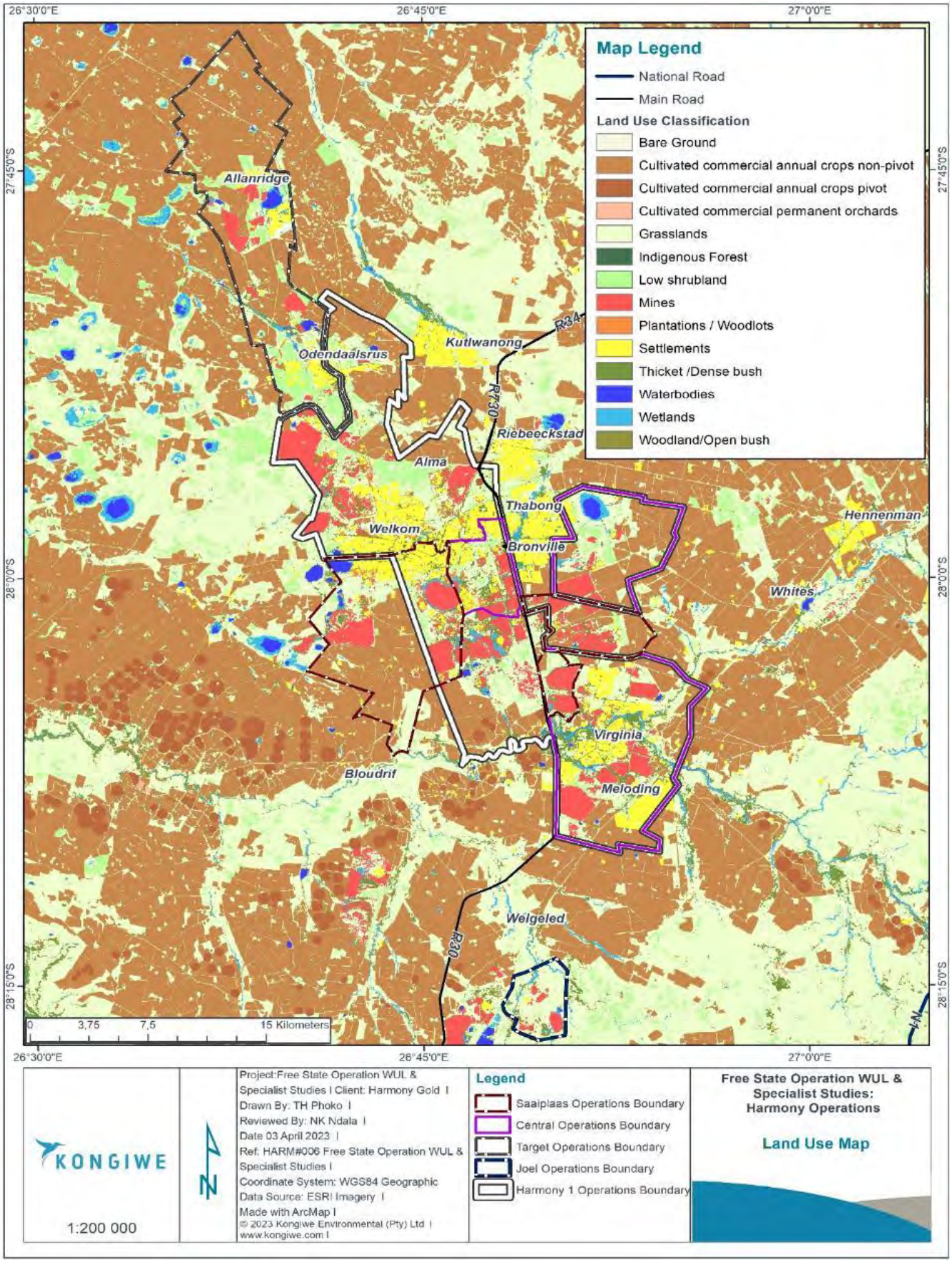


Figure 3-2: Land cover map

3.2.4 Geology and Soils

The study area is predominantly on aeolian and colluvial sand overlying sandstone, mudstone and shale of the Karoo Supergroup, as well as older Ventersdorp Supergroup andesite and basement gneiss in the north. The area also consists of sedimentary mudstones and sandstone mainly of the Adelaide Subgroup (Beaufort Group, Karoo Supergroup), as well as those of the Ecca Group (Karoo Supergroup). Deep sandy to clayey (but mostly coarse sand) alluvial soils are also found in the project area. Some of the soils found in the project area are Avalon, Westleigh, Clovelly, Oakleaf, Dundee and Shortlands. Glenrosa and Mispah soil forms were identified in the Vaal River floodplain (Bezuidenhout et al.,1994).

Land types found in the project area include Bd, Bc, Ae, Ba and Ea land types.

Strata of the Karoo Supergroup, represented by argillaceous rocks (such as shale, siltstone and mudstone) of the Ecca Group and the arenaceous rocks (such as sandstone) of the Beaufort Group underlie the Harmony Free State Operations. Intergranular and fractured aquifers represent the hydro geological environment of the area (WRC, 2013).

The identified aquifers at the Harmony Free State Operations include the shallow aquifer and the deep aquifer. The shallow aquifer is found near the surface of the weathered Karoo formations, while the deep aquifer is found in the fractured and faulted Witwatersrand and Ventersdorp sequences. The deep aquifer contains poor water and is not interconnected to the shallow aquifer (SRK Consulting, 2020).

4 METHODOLOGY

4.1 Site Investigations

Several site investigations of the project area were undertaken during 2022. The purpose of the site investigations was to assess the hydrological characteristics of the area, and to conduct a GN R704 audit of the operations.

4.2 Floodline Determination

4.2.1 Elevation Data

Lidar data of the project area flown in June 2022 was supplied by Kongiwe and was used to delineate catchments as well as in the hydraulic modelling of the floodlines.

4.2.2 Peak Flows

The following methods were used to estimate the peak flows:

4.2.2.1 Rational Method

The Rational method is based on the following equation:

$$Q_T = \frac{C\ I\ A}{3.6}$$

where:

Q_T = Peak flow for a recurrence interval e.g. a 1:100 year flood (m^3/s)

C = Runoff coefficient (dimensionless)

I = Average rainfall intensity over the catchment (mm/hour)

A = Catchment area contributing to the peak flow (km²)

3.6 = Conversion factor

The runoff coefficient "C" is calculated by specifying the percentage area covered by different physical characteristics of the contributing catchment. This includes the vegetation, slope, soil permeability and land use characteristics.

The average rainfall intensity "I" was calculated by dividing the gridded storm rainfall depths obtained from Smithers and Schulze (2002) by the time of concentration (Tc). The Tc is the amount of time it takes for water to travel from the hydraulically most remote point in the contributing catchment to the catchment outlet.

The contributing catchment area "A" was calculated by delineating a catchment for the peak flow point from the Digital Terrain Model (DTM).

A Microsoft Excel spreadsheet (Gericke and du Plessis, 2013) was used to perform the calculations based on the South African National Roads Agency Limited (SANRAL) procedure (SANRAL, 2013).

The Rational method is based on the following key assumptions:

- Rainfall has a uniform area distribution across the total contributing catchment;
- Rainfall has a uniform time distribution for at least a duration equal to the Tc;
- The peak discharge occurs when the total catchment contributes to the flow occurring at the end of the critical storm duration, or Tc;
- The runoff coefficient "C" remains constant for the storm duration, or Tc; and
- The return period of the peak flow is the same as that of the rainfall intensity.

The Rational method is generally applicable for catchments smaller than 15 km², however, it has been successfully applied to much larger catchments.

4.2.2.2 Empirical Deterministic Peak Discharge Method (Midgley and Pitman)

The Empirical Deterministic Peak Discharge method (also referred to as the Midgley and Pitman method) is based on the following formula:

$$Q_T = 0.0377 K_T P A^{0.6} C^{0.2}$$

Where:

Q_T = Peak flow (m³/s)

K_T = Constant value for veld type

A = Catchment area (km²)

P = Mean annual precipitation (mm)

C = Catchment parameter with regards to reaction time

More details on the method can be obtained from Pitman and Midgley (1971).

4.2.2.3 SCS Method

The calculation of peak discharge by the Soil Conservation Service (SCS) method is based on the triangular unit hydrograph concept. This unit hydrograph represents the temporal distribution of stormflow for an incremental unit depth of stormflow, ΔQ, occurring in a unit duration of time, ΔD.

Peak discharge for an increment of time ΔD is defined by the equation:

$$\Delta q_p = \frac{0.2083\mathrm{A}\Delta Q}{\frac{\Delta D}{2} + L}$$

Where:

Δq_p = Peak discharge of incremental unit hydrograph (m³/s)

A = Catchment area (km²)

ΔQ = Incremental stormflow depth (mm)

ΔD = Unit duration of time (h), used with the distribution of daily rainfall to account for rainfall intensity variations

L = Catchment lag (h), an index of the catchment's response time to the peak discharge

To determine the hydrograph response to a given rainfall total, incremental hydrographs are superimposed according to the distribution of stormflow over time, as determined from the time distribution of rainfall intensity and the stormflow response characteristics of the catchment. More details on the SCS method can be found in Schmidt and Schulze (1987).

4.2.3 Software

The following software's were used:

- The peak flows were calculated using the Design Flood Estimation Tool (Gericke & du Plessis, 2013);
- ArcMap 10.2 is a GIS software programme used to view, edit, create and analyse geospatial data. ArcMap was used to view spatial data and to create maps. Its extension 3D Analyst was used for terrain modelling purposes, for converting the contour data into a DTM grid format;
- HEC-GeoRAS utilises the ArcMap environment and is used for the preparation of geometric data (cross-sections, river profile, banks and flow paths) for input into the HEC-RAS hydraulic model. It is further used in post processing to import HEC-RAS results back into ArcMap, to perform flood inundation mapping; and
- HEC-RAS was used to perform hydraulic modelling. HEC-RAS is a hydraulic programme used to perform one-dimensional hydraulic calculations for a range of applications, from a single watercourse to a full network of natural or constructed channels.

4.2.4 Hydraulic Model Setup

Development of the hydraulic model included the following steps:

- Preparation of geometric data (cross-sections, stream centre line, bank lines and flow paths) in HEC-GeoRAS;
- Importing of geometric data into HEC-RAS;
- Entering hydraulic structures and model parameters in HEC-RAS;
- Performing steady, mixed flow (combination of subcritical, supercritical, hydraulic jumps and drawdowns) modelling within HEC-RAS to calculate the flood water elevations at cross-sections; and
- Importing flood level elevations at cross-sections into HEC-GeoRAS to perform floodplain delineations.

4.2.5 Assumptions and Limitations

The following were assumptions and limitations for the floodline determination:

- The lidar data provided did not cover Tributary 4 nor the section of the Sand River into which Tributary 4 flows into. For this area, a 30 m spatial resolution Copernicus DEM was used for modelling purposes; and
- The floodlines are indicative for the purposes of the WULA and should not be used for design purposes.

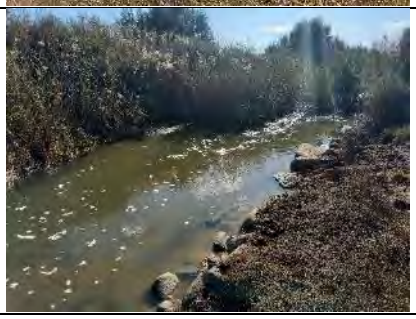
4.2.6 Manning's Roughness Coefficients

The selected Manning's roughness coefficients for the rivers flowing through the Harmony Operations are indicated in Table 4-1. The Manning's roughness coefficients were estimated from Chow (1959).

Table 4-1: Selected Manning's roughness coefficients for the rivers flowing through the Harmony Operations

River	Photograph	Manning's Roughness Coefficient	
		Channel	Riverbanks & Floodplains
Doring River		0.05	0.08

River	Photograph	Manning's Roughness Coefficient	
		Channel	Riverbanks & Floodplains
Theronspruit		0.05	0.08
Tributary of Doring River	–	0.05	0.08
Sand River		0.04	0.06
Rietspruit		0.04	0.06
Tributary 1 of Sand River	–	0.04	0.06
Tributary 2 of Sand River (upstream)		0.06	0.06

River	Photograph	Manning's Roughness Coefficient	
		Channel	Riverbanks & Floodplains
Tributary 2 of Sand River (downstream)		0.04	0.06
Tributary 3 of Sand River		0.05	0.08
Tributary 4 of Sand River	–	0.04	0.06
Tributary 1 of Sandspruit		0.06	0.06

4.3 GN R704 Audit

A review of reports, documents and plans was undertaken prior to the site visits. Based on the reviews, an audit plan and checklist were compiled which formed the basis of the audit. During the audit, interviews and discussions were held with relevant mine personnel. Photographs and Global Positioning System (GPS) points were also taken.

4.3.1 Assumptions and Limitations

The following were assumptions and limitations of the GN R704 audit:

- The auditing was done on a sample basis, however, all effort to visit all areas was undertaken as far as possible; and
- No waste classification or geochemical assessment of the waste rock, tailings material, mud stockpiles (from underground dams), etc. was available, and therefore, it was not possible to determine the pollution potential of the waste.

A copy of GN R704 regulations is provided in Appendix A.

4.4 Conceptual Stormwater Management Plan

The development of the Stormwater Management Plan (SWMP) was undertaken in accordance with the DWS Best Practice Guideline G1: Storm Water Management and GN R704 regulations. The primary purpose of the SWMP was to ensure that clean (non-impacted water) and dirty water (mine impacted water) are separated and managed in accordance with the above-mentioned guideline and regulations.

The SWMP was prepared using ArcMap software. The lidar data provided by Kongiwe was used to determine the slopes, flow directions and to delineate catchments.

5 JOEL OPERATIONS

5.1 Description of Operations

The infrastructure that forms part of the Joel Operations is shown on Figure 5-1. Underground mining was initiated in 1978 and the Joel Operations have an approximate Life of Mine (LoM) until 2029. Ore from the Joel mine is hoisted to the surface at the Joel North Shaft (also known as the Joel 1 Shaft or Taung North Shaft) and is then transported to the Harmony 1 Plant via truck for processing. The Joel South Shaft (also known as the Joel 3 Shaft or Taung South Shaft) is used as a man and material decline shaft. The Joel Plant is currently non-operational and is under care and maintenance. Table 5-1 provides a summary of the current activities undertaken at the Joel Operations and has been modified from SRK (2020c).

Table 5-1: Summary of activities undertaken at the Joel Operation

Aspect	Description
Mining	
Underground mining	• Mining at the Joel Operations is undertaken at Joel 1 North and Joel 3 South shafts. • The total run of mine volume is provided by underground mining. • The Beatrix Reef and VS5 Reef are mined. • Mining depths are currently approximately 1 300 m below surface.
Beneficiation	
Metallurgy plants	• Mined ore is processed at the Harmony 1 Plant. • The Joel Plant is currently non-operational. • Gold is smelted at Rand Refinery.
Water and waste management systems	
Water supply	The Joel Operations receive water supply from Sedibeng Water, which is used for domestic purposes and supplements mining and metallurgical purposes.
Dirty (waste) water containment and release	• Dirty water (process water) is as far as possible contained in dirty water containment facilities. • Dirty water is reused or evaporated.
Clean water diversions	Clean water diversions are partially in place at the shafts and processing areas to direct runoff from the surrounding catchment, away from the dirty areas.

Waste rock	Waste rock from the shafts is sent to the Joel South and Joel North Waste Rock Dumps (WRDs). No waste rock is currently being processed at the Joel Operations.
Slimes Dam Complex	The Slimes Dam Complex is not receiving tailings as the Joel Plant is non-operational.
Evaporation Dams	The Evaporation Dams are used to evaporate excess groundwater water from the South Shaft.
Domestic and industrial waste	Standard operating procedures have been developed for waste management at the Joel Operations. • Domestic waste generated at the Joel Operations is taken off-site to a registeredlandfill site. • Industrial waste is handled at the shaft and processing areas in designated waste areas. Scrap metal, wood and plastic are recycled through the Salvage Yard. • Hazardous waste is handled by the appointed contractor and is transported off-site to a registered hazardous waste facility.
Sewage	• Sewage at the Joel Operations is treated at the Joel Sewage Treatment Plant (STP). • Treated effluent is discharged to the Theronspruit.
Support infrastructure	
General infrastructure	The support infrastructure associated with the Joel Operations includes: • Administration offices. • Change houses. • Engineering workshops. • Salvage yard.

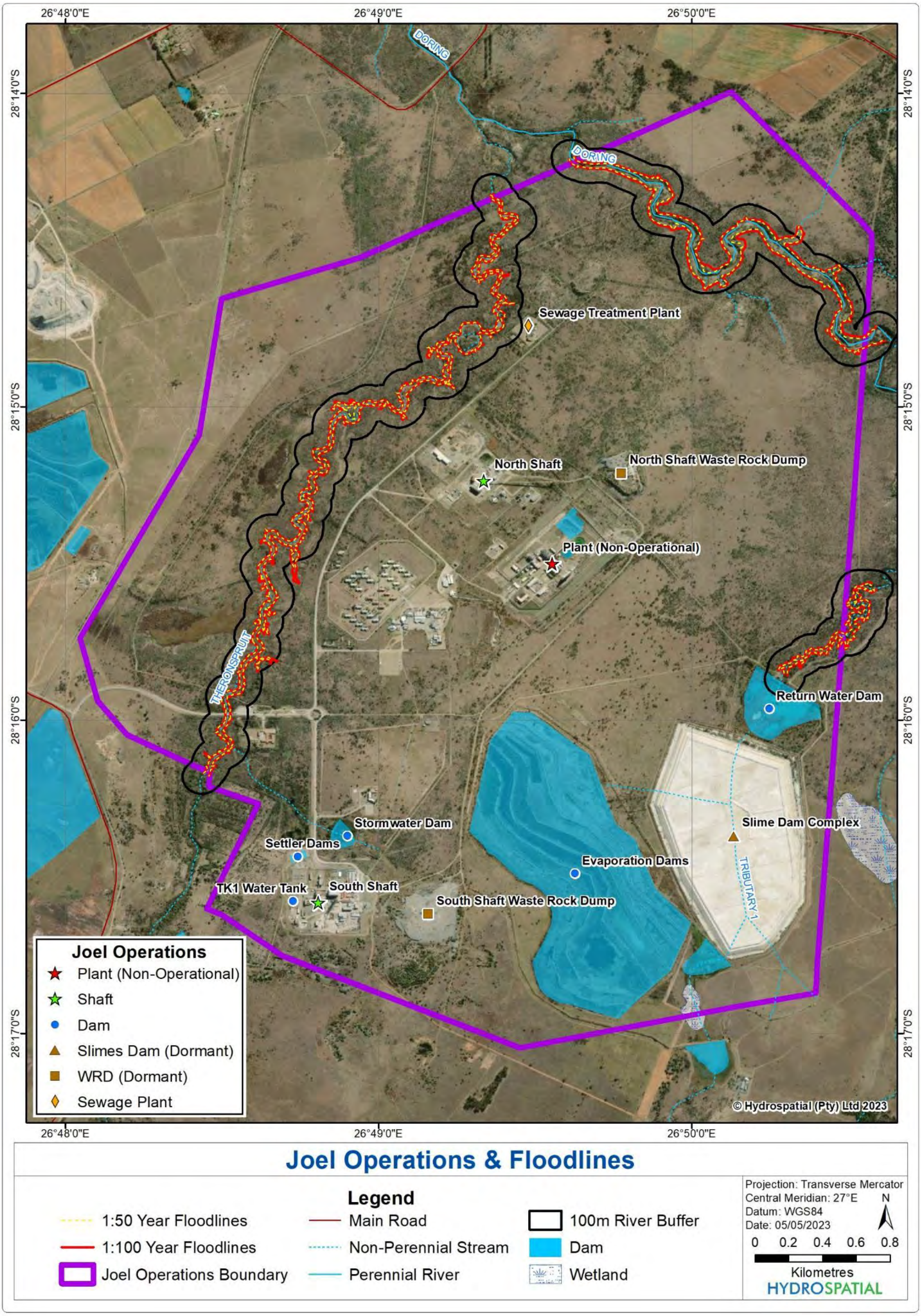


Figure 5-1: Joel Operations and floodlines

5.2 Floodlines

The floodlines and 100 m buffers have been determined for the rivers and streams that flow through the Joel Operations. These include:

- The Doring River which flows in a north-westerly direction near the north-eastern boundary of the operations;
- The Theronspruit that flows in a north-easterly direction on the western side of the operations; and
- A non-perennial stream (Tributary 1) that flows in a north-easterly direction along the eastern boundary of the operations. This stream is a tributary of the Doring River. The Slimes Dam Complex and Return Water Dam (RWD) have been constructed within this stream.

A summary of the estimated peak flows that were used to determine the floodlines is provided in Table 5-2, whilst the floodlines and 100 m river buffers are shown on Figure 5-1.

Table 5-2: Peak flows used to determine the floodlines for the Saaiplaas Operations

River	Catchment Area (km^2)	Method	1:50 Year Peak Flow (m^3/s)	1:100 Year Peak Flow (m^3/s)
Doring River	250.2	Rational	214	289
		SCS	224	278
		Midgley & Pitman	230	291
		Average	**223**	**286**
Theronspruit	47.3	Rational	88	118
		SCS	96	118
		Midgley & Pitman	93	117
		Average	**92**	**118**
Tributary 1 of Doring River	12.8	Rational	25	47
		SCS	39	48
		Midgley & Pitman	40	50
		Average	**35**	**48**

The RWD and Slimes Dam Complex have been constructed within a non-perennial tributary of the Doring River and therefore located within 100 m of a river. A clean water channel/diversion has been constructed upstream to the south of the Slimes Dam Complex.

5.3 GN R704 Audit

Figure 5-2 indicates the location of the non-compliances with GN R704, whilst Table 5-3 provides a summary of the non-compliances and recommendations for improvement at the Joel Operations.

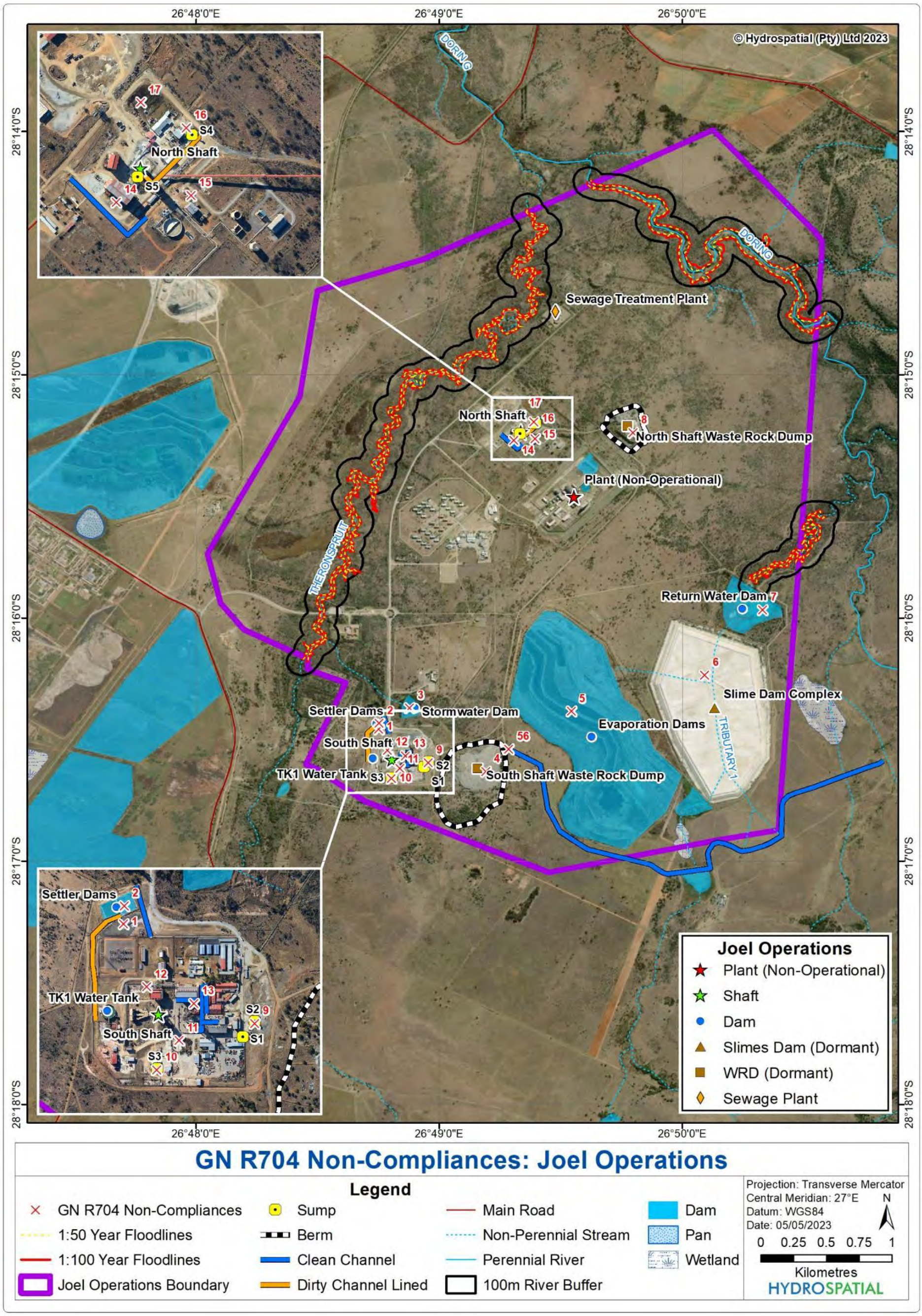


Figure 5-2: Location of the GN R704 non-compliances at the Joel Operations

Table 5-3: Joel Operations GN R704 non-compliances and recommendations

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
Joel – Settler Dams	1	Regulation 7(a) – stockpiling of dirty material desilted from the Settler Dams on an unlined and uncontained area. 	Dirty material must be stockpiled on a lined and contained area.
Joel – Settler Dams	2	Regulation 8(a) – No warning signs in prominent locations were noted at the Settler Dams. The Settler Dams are not fenced off, however, they are within the mine boundary fence. 	Warning signs that indicate no drinking, no swimming, no fishing, etc. should be erected at the facility.
Joel – Settler Dams	2	Regulation 6(d) – The Settler Dam on the eastern side was noted to be heavily silted. 	Desilt dams on a more frequent basis.
Joel – Stormwater Dam	3	Regulation 8(a) – No warning signs in prominent locations were noted at the Stormwater Dam.	Warning signs that indicate no drinking, no swimming, no fishing, etc. should be erected at the facility.
Joel – Stormwater Dam	3	Regulation 6(c), 6(d) and 7(a) – The Stormwater Dam is unlined and receives seepage from the South WRD.	• Seepage from the South WRD should be contained at the WRD and if at all possible, conveyed to the Evaporation Dams or Settler Dams. • The facility is present on Landsat imagery that pre-dates June 1999 when GN R704 was enacted, and therefore it is likely that this dam was already being used to contain dirty water. Exemption should be applied for.
Joel – South WRD	4	Regulation 5 – Waste rock that may potentially be hazardous has been used in the construction of a berm around the South WRD. 	A waste classification (geochemical assessment) should be undertaken on the waste rock material. Should the waste classification indicate that the material is non-hazardous, then exemption from GN R704 should be applied for, for the use of waste rock in the construction of berms as well as for any other purposes at the mine (e.g. road construction, embankments, dams, etc.). It should be noted that the WRD is visible on aerial imagery that pre-dates June 1999 when GN R704 was enacted.
Joel – North and South WRD	4 & 8	Regulation 6(c) and 7(a) – The North and South WRDs are not lined and may potentially seep hazardous water.	The facilities are present on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Joel – Evaporation Dams	5	Regulation 6(c) and 7(a) – The Evaporation Dams are not lined and may potentially seep hazardous water.	The facility is present on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Joel – Evaporation Dams	5	Regulation 8(a) – No warning signs in prominent locations were noted at the Evaporation Dams.	Warning signs that indicate no drinking, no swimming, no fishing, etc. should be erected at the facility.
Joel – Slimes Dam Complex and RWD	6 & 7	Regulation 6(c) and 7(a) – The Slimes Dam Complex and RWD are not lined and may potentially seep hazardous water.	The facilities are present on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Joel – Slimes Dam Complex and RWD	6 & 7	Regulation 4(a) – The Slimes Dam Complex and RWD have been constructed in a non-perennial stream and are therefore located within 100 m of a watercourse.	The facilities are present on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Joel – Underground mining	–	Regulation 4(b) – Underground mining is likely to have taken place beneath a watercourse.	Mining pre-dates GN R704. Exemption should be applied for.

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
Joel – South Shaft Silo Sump	9	Regulation 6(d) – The Silo Sump was noted to be heavily silted. 	The Silo Sump should be cleaned on a more frequent basis as it receives sludge/mud from the underground dams.
Joel – South Shaft Wash Bay Sump	10	Regulation 6(d) – The Wash Bay sump (S3) was noted to have overflowed. This is likely due to the pump not having started or the sump being under sized. 	It is recommended that if the pump is manually operated that it is converted to an automatic pump, or that the sump capacity is increased.
Joel – South Shaft Emulsion Bay	11	Regulation 6(d) – The Emulsion Bay was noted to not be fully bunded. 	The Emulsion Bay should be fully bunded.
Joel – South Shaft Oil Store	12	Regulation 6(d) – The Oil Store near the 3# Compressor House was noted to be leaking oil from a hole in the wall. 	The hole in the wall should be repaired.
Joel – South Shaft	13	Regulation 6(c) – Hydrocarbon spills were noted near the Winder House which drains to clean channel CC4. 	Hydrocarbon spills within clean areas should be cleaned up immediately. Alternatively, should these areas receive a lot of hydrocarbon spills then they should be managed as dirty areas.
Joel – North Shaft	14	Regulation 6(d) – A spill from a damaged wall was noted at the Oil Bay at the North Shaft. 	The wall of the Oil Bay should be repaired.
Joel – North Shaft	15	Regulation 7(a) – Informal ponding of water from water flowing from the Compressor House at the North Shaft. The growth of vegetation where ponding occurs indicates that this is likely to be a regular occurrence.	Water flowing from the Compressor House should be captured in a formal facility such as a sump.

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
			
Joel – North Shaft	16	Regulation 6(c) – Washing of vehicles upslope of the Wash Bay Sumps was noted to be taking place on an unlined area. 	The area where vehicles and machinery are washed should be lined up to the Wash Bay Sumps to prevent seepage.
Joel – North Shaft	17	Regulation 7(a) – Informal ponding of water from what appeared to be a domestic washing area. 	This water should not be allowed to drain to the environment and should be captured in a formal facility such as a sump or a tank.
Joel – Clean channel/diversion	56	Regulation 6(a) – The clean water channel/diversion that diverts water around the Slimes Dam Complex discharges towards the South WRD. This may result in clean water becoming contaminated.	The clean channel should be extended around the South WRD to prevent clean water from potentially becoming contaminated.

5.4 Conceptual Stormwater Management Plan

The existing and proposed stormwater measures at the Joel Operations are shown on Figure 5-3 and are described below. It should be noted that the Joel Plant is non-operational and is strictly access controlled and was therefore not visited.

5.4.1 Existing Stormwater Measures

5.4.1.1 South Shaft

The South Shaft is mostly concrete lined. The existing stormwater measures consist of the following:

- A lined dirty water channel (DC1) that conveys overflows from the TK1 Tank to the Settler Dams. The TK1 Tank stores excess groundwater, which is treated and then reused underground. Water from the TK1 Tank is also pumped to the Evaporation Dams;
- Lined Settler Dams which receive overflows from the TK1 Tank as well as mud/sludge pumped from the underground dams via the Silo Sump (S2);
- A lined clean water channel (CC1) which conveys clean water runoff from the shaft area towards the Theronspruit. This channel also receives overflows from the Settler Dams should they overflow;
- Unlined Stormwater Dam which receives runoff from the shaft area and overflows towards the Theronspruit;
- Sump S1 that collects runoff from the eastern part of the shaft area and pumps to the Silo Sump (S2);
- Silo Sump (S2) that receives sludge/mud from the underground dams and which is then pumped to the Settler Dams. The Silo Sump also receives water from Sump S1;
- Sump S3 that collects water from the Wash Bay and Change Houses and pumps to S1;
- Clean channels CC3 to CC5 which drain the shaft area towards the Theronspruit; and
- Clean channel CC6 which drains the admin and office area towards the Stormwater Dam.

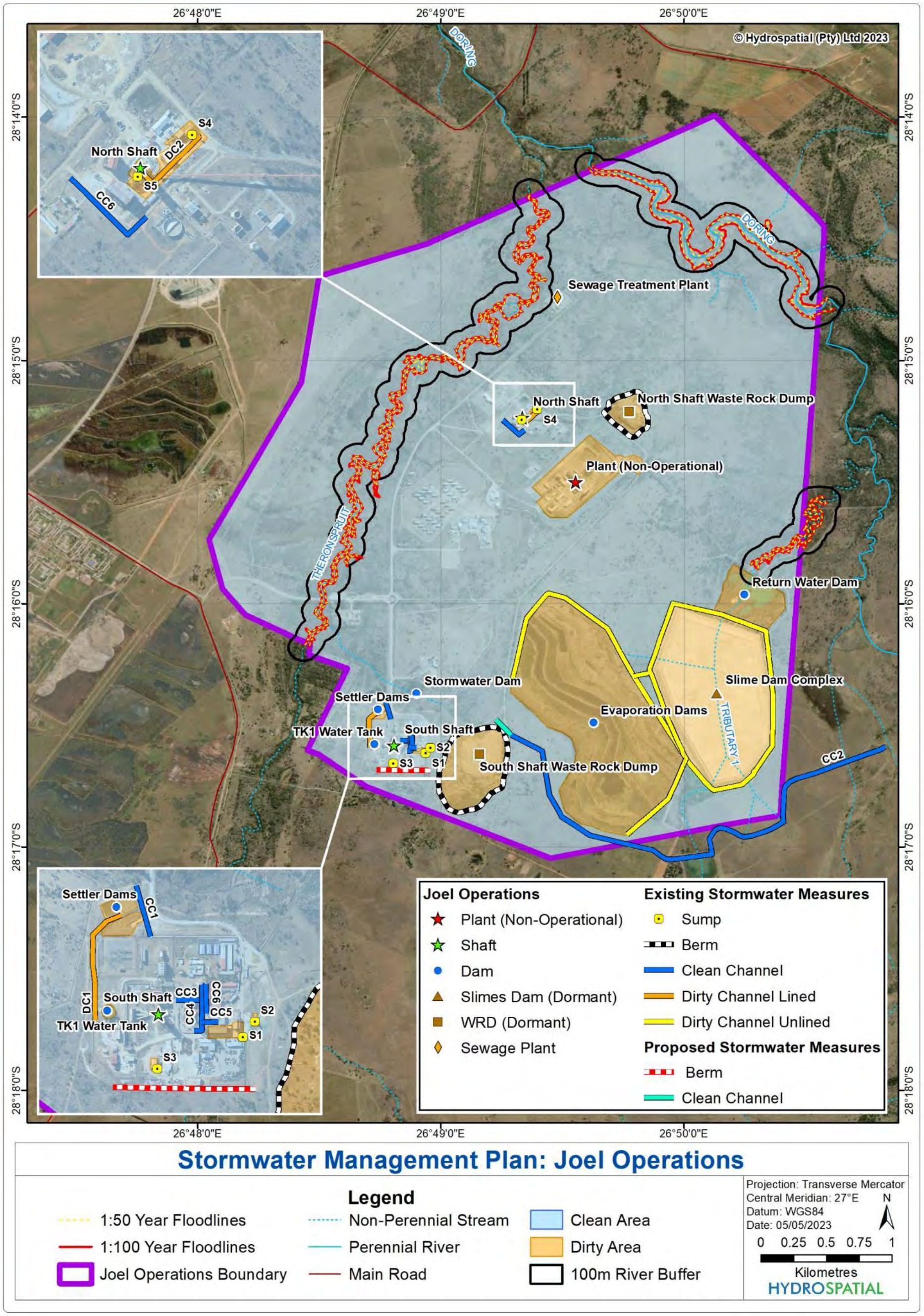


Figure 5-3: Conceptual stormwater management plan for the Joel Operations

5.4.1.2 North Shaft

The North Shaft consists of the following stormwater measures:

- Clean water channel CC6 to prevent upslope runoff from flowing towards the shaft;
- Lined Wash Bay Sumps S4 that receives runoff from the shaft area, Wash Bays and from the cleaning of vehicles and machinery;
- Lined dirty water channel DC2 that conveys runoff from the shaft area to the Wash Bay Sumps; and
- Sump S5 near the shaft that is connected to channel DC2.

5.4.1.3 Other Areas

The existing stormwater measures at other areas at the Joel Operations include:

- Berms around the North and South Waste Rock Dumps (WRD) to contain runoff from those facilities;
- Clean water channel CC2 that diverts upslope runoff around the Slimes Dam Complex and Evaporation Dams;
- Toe paddocks and solution trench around the Slimes Dam Complex, that captures and conveys runoff and seepage to the RWD; and
- Evaporation Dams that receive and evaporate excess groundwater.

5.4.2 Clean and Dirty Areas

The dirty areas at the Joel Operations include the Slimes Dam Complex, WRDs, RWD and sections of the shafts. Dirty areas should be contained to ensure that they do not flow or seep into clean areas. The remaining areas should be managed as clean areas, which should not be contaminated by dirty areas, or flow into dirty areas. Figure 5-3 shows the clean and dirty areas at the Joel Operations.

5.4.3 Proposed Stormwater Measures and Recommendations

The following are proposed stormwater measures and recommendations for the Joel Operations:

- A berm is proposed on the southern boundary of the South Shaft, to ensure that no upslope external clean water flows into the shaft area;
- All sump pumps should be installed with automatic water level sensors to ensure that the sumps do not overflow;
- For the shaft areas to be operated as clean areas, it is of outmost importance that all hydrocarbon and hazardous areas are lined and contained, and that they report to dirty water containment facilities. Hydrocarbon spills as well as any other hazardous spills at the shafts, must be cleaned up immediately for these areas to be operated as clean areas. This may require more frequent inspections and for the drivers of machinery and vehicles to be equipped with spill kits;

- Sump S1 should be monitored during high rainfall events. If it is found that this sump overflows on a regular basis, then the size of the sump should be increased. Alternatively, S3 should be fitted with a big enough pump that ensures that the sump does not overflow. The same is proposed for S2;
- Where the berms surrounding the WRDs have been opened for road access, it is proposed that ramps are built across the roads so that runoff is contained within the footprint area of the WRDs;
- The water levels of the Evaporation Dams, RWD, Settler Dams and Stormwater Dam should be monitored and recorded;
- The clean water channel/diversion CC2 should be extended so that it does not discharge towards the South WRD; and
- The recommendations in Table 5-3 should be implemented.

6 SAAIPLAAS OPERATIONS

6.1 Description of Operations

The infrastructure that forms part of the Saaiplaas Operations is indicated on Figure 6-1. It should be noted that the boundary of the Saaiplaas Operations overlaps with the Central and Harmony 1 Operations. Underground mining at the Saaiplaas Operations was initiated in 1950, however, no underground mining currently occurs. Tailings and waste rock are currently reclaimed and processed at the Saaiplaas Plant The approximate life of mine (LoM) for the current operations is until approximately 2030. Table 6-1 provides a summary of the current activities undertaken at the Saaiplaas Operations (SRK, 2020d).

Table 6-1: Summary of activities undertaken at the Saaiplaas Operations

Aspect	Description
Mining	
Underground mining	• All eleven shafts at the Saaiplaas Operations have been decommissioned. These shafts are Brand 1, Brand 2, Brand 3, Brand 5, Saaiplaas 2, Saaiplaas 3, St Helena, St Helena 2, St Helena 7, St Helena 8 and St Helena 10 shafts. • Activity at the decommissioned shaft areas is limited to the reclamation of waste rock for processing at the plant.
Beneficiation	
Metallurgy plants	• Ore from the recovered waste rock and the reclaimed tailings is processed at the Saaiplaas metallurgical plant. • Gold is sent to the Harmony 1 Plant for smelting. • Waste products from the Saaiplaas metallurgical plant are deposited at the St Helena 1, 2, 3 tailings storage facilities (TSFs).
Water and waste management systems	
Water supply	The Saaiplaas Operations receive water supply from Sedibeng Water, which is used for domestic purposes, and supplements mining and metallurgical purposes.

Dirty (waste) water containment and release	• Dirty water (process water) is contained in process water dams and stormwater dams. • Dirty water runoff from the shafts and processing areas is contained in the dirty water containment facilities, including return water dams. • Water from the dirty water containment facilities including the return water dams is reused in the process.
Clean water diversions	Clean water diversions are in place at the shafts and processing areas to direct runoff from the surrounding catchment, away from the dirty areas.
Waste rock	• Waste rock deposition is currently not occurring at four waste rock dumps; these dumps are being processed: Brand 2 Shaft waste rock dump, Saaiplaas 2 Shaft waste rock dump, and Saaiplaas 3 Shaft waste rock dump. • Waste rock deposition has ceased at the following nine waste rock dumps where the dumps have been fully recovered and only the footprint area remains: Brand 1 Shaft waste rock dump, Brand 3 Shaft waste rock dump, Brand 5 Shaft waste rock dump, St Helena Shaft waste rock dump, St Helena 2 Shaft waste rock dump, St Helena 7 Shaft waste rock dump, St Helena 8 Shaft waste rock dump, St Helena waste rock dump 1, St Helena waste rock dump 2. • St Helena No.10 waste rock dump and St Helena No. 2 waste rock dump are dormant.
Tailings	• Tailings from Saaiplaas Plant is transported via pipeline to the St Helena 1, 2, 3 tailings facility. • The St Helena 1, 2, 3 tailings facility will continue to receive tailings until the design life of the facility. • Re-pulped tailings from the Slimes Dam 21 (H3) and the Brand A tailings complex are transported to the Saaiplaas Plant via pipeline for reprocessing.
Domestic and industrial waste	Standard operating procedures have been developed for waste management at the Saaiplaas Operations. • Domestic waste generated at the Saaiplaas Operations is taken off-site to a registered landfill site. • Industrial waste is handled at the shaft and processing area in designated waste areas. Scrap metal, wood and plastic are recycled through the Salvage Yard.
	• Hazardous waste is handled by the appointed contractor, currently Micro Trading, and is transported off-site to a registered hazardous waste facility.
Sewage	Sewage from the Saaiplaas Operations is directed to the municipal sewage treatment plant.
Support infrastructure	
General infrastructure	The support infrastructure associated with the Saaiplaas Operations includes: • Administration offices • Change houses • Engineering workshops • Salvage yard.

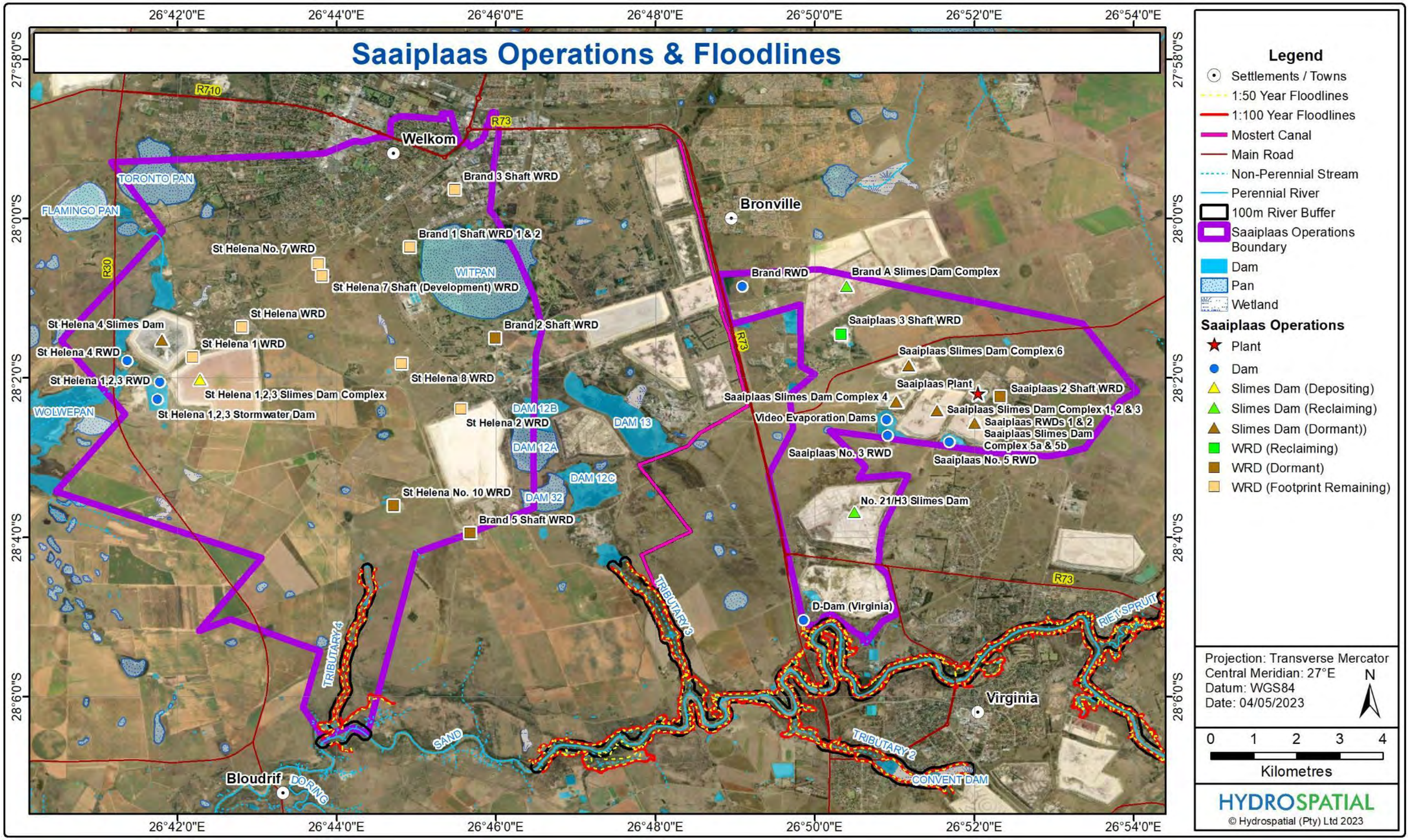


Figure 6-1: Saaiplaas Operations and floodlines

6.2 Floodlines

The floodlines and 100 m buffers have been determined for the rivers and streams that flow through the Saaiplaas Operations. These include:

- The Sand River which flows in a westerly direction along the southern boundary of the operations; and
- A non-perennial stream (Tributary 4) which begins below the St Helena WRD No. 10 and flows in a southerly direction towards the Sand River.

A summary of the estimated peak flows that were used to determine the floodlines is provided in Table 6-2, whilst the floodlines and 100 m river buffers are shown on Figure 6-1.

Table 6-2: Peak flows used to determine the floodlines for the Saaiplaas Operations

River	Catchment Area (km^2)	Method	1:50 Year Peak Flow (m^3/s)	1:100 Year Peak Flow (m^3/s)
Sand River	6 472.81	Rational	1 634	2 194
		SCS	1 756	2 068
		Midgley & Pitman	1 684	2 127
		Average	**1 691**	**2 130**
Tributary 4 of Sand River	12.99	Rational	43	57
		SCS	59	73
		Midgley & Pitman	56	71
		Average	**53**	**67**

None of the infrastructure at the Saaiplaas Operations is located within the floodlines or within 100 m of a river.

6.3 GN R704 Audit

Figure 6-2 and Figure 6-3 indicate the location of the non-compliances with GN R704, whilst Table 6-3 provides a summary of the non-compliances and recommendations for improvement at the Saaiplaas Operations.

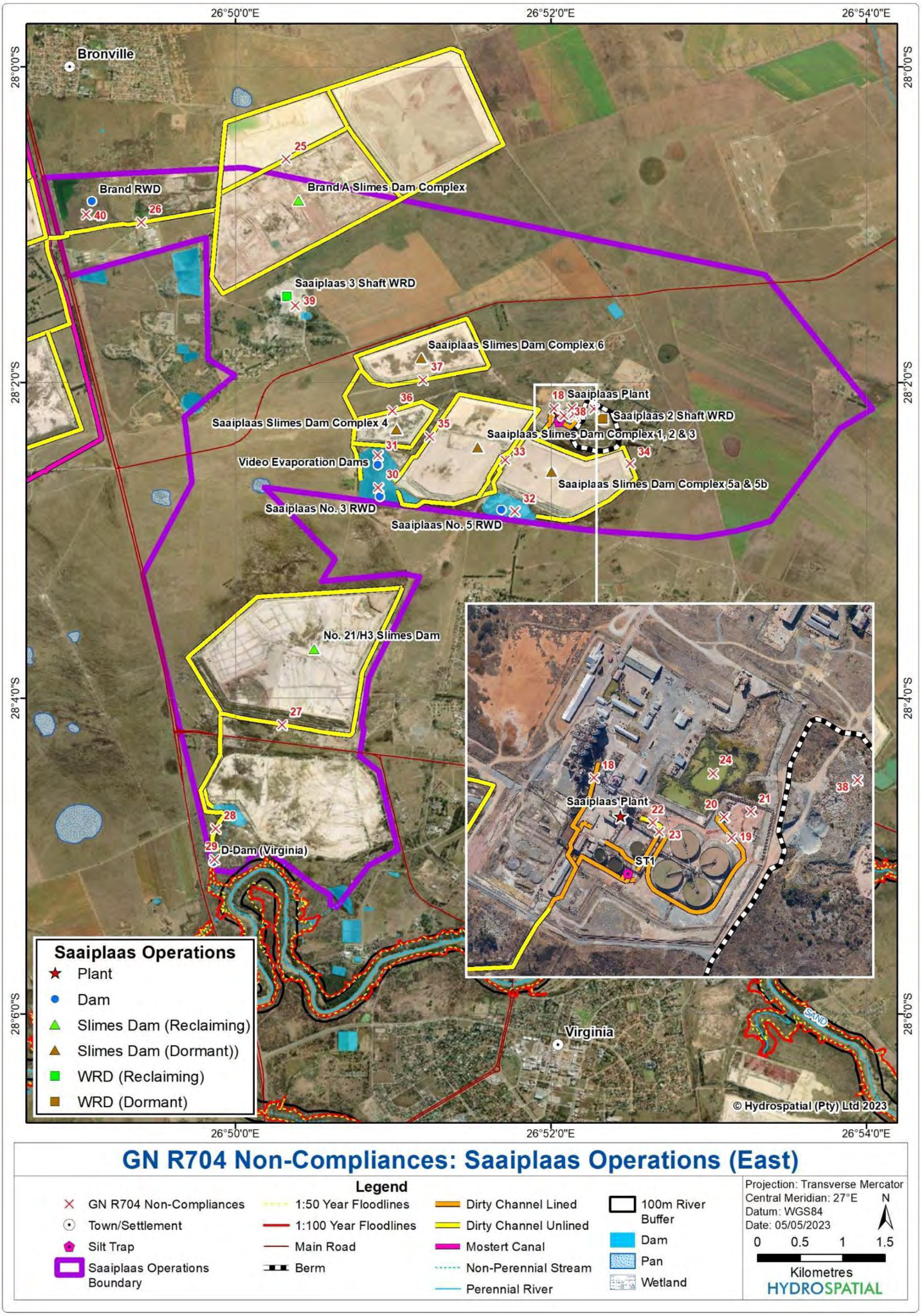


Figure 6-2: Location of the GN R704 non-compliances at the Saaiplaas Operations (east)

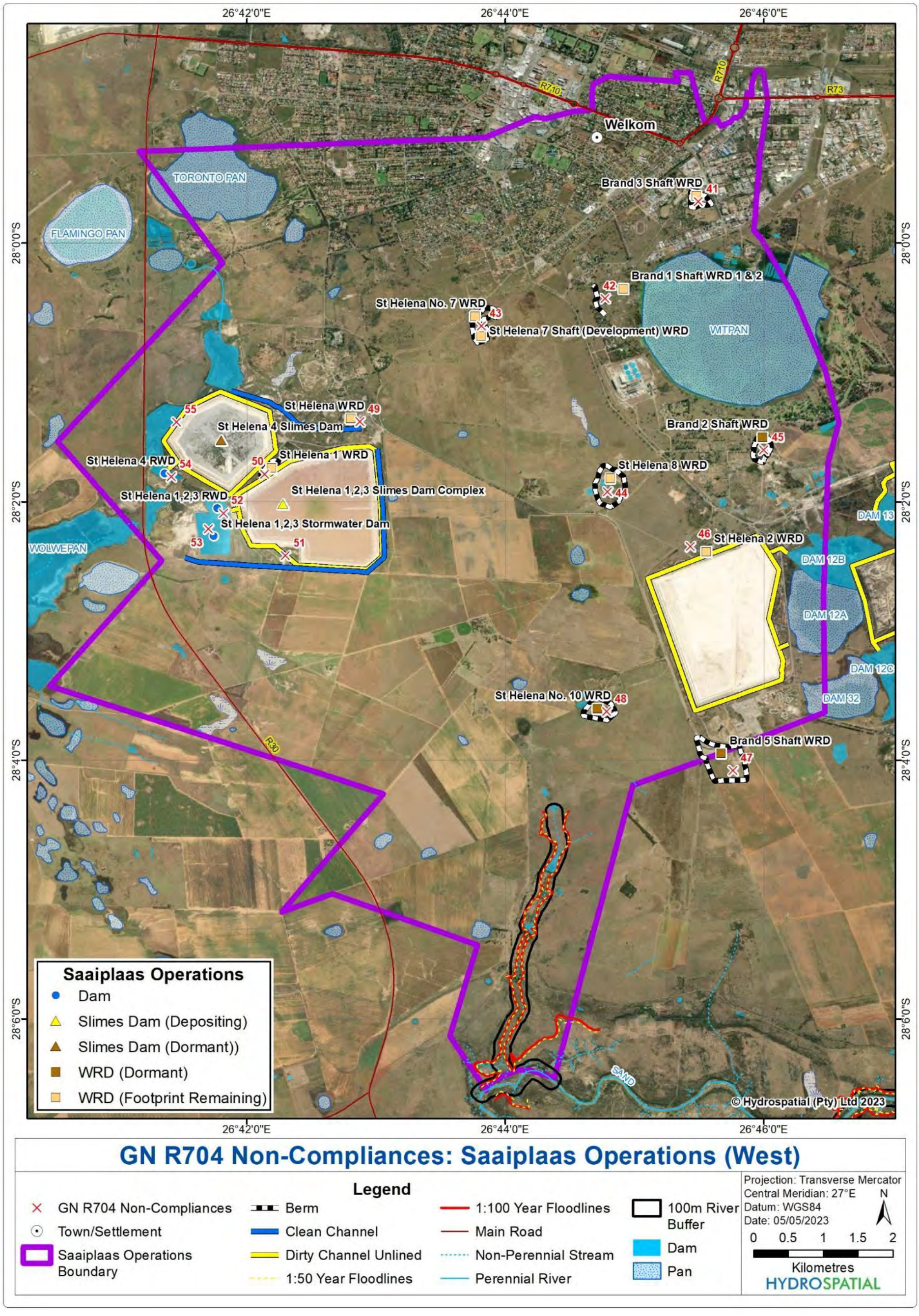


Figure 6-3: Location of the GN R704 non-compliances at the Saaiplaas Operations (west)

Table 6-3: Saaiplaas Operations GN R704 non-compliances and recommendations

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
Saaiplaas – Plant	18, 19 & 23	Regulation 6(d) – The channels at the plant were noted to be silted. The channels are cleaned approximately once per year. 	The channels at the plant should be inspected and cleaned on a more frequent basis. It is recommended that this is done at least on a monthly basis.
Saaiplaas – Plant	20	Regulation 6(d) – The Wash Bay is not contained at its entrance and therefore dirty runoff from cleaning reports to bare ground. 	It is recommended that a concrete ramp is erected at the entrance of the Wash Bay to contain runoff from this facility.
Saaiplaas – Plant	21	Regulation 6(c), 6(d) and 7(a) – Stockpiling of potentially hazardous material on an unlined area.	Stockpiling of potentially hazardous material should take place on a lined and contained area.
Saaiplaas – Plant	22	Regulation 6(c), 6(d) and 7(a) – Unlined dirty water channel from the Wood Chip Screening Area. 	The channel should be lined as it is a dirty water channel.
Saaiplaas – Plant	24	Regulation 6(c), 6(d) and 7(a) – The demolished milling area at the Saaiplaas Plant has left a depression that collects water that may seep or overflow towards the plant area. 	The demolished milling area at the Saaiplaas Plant should be rehabilitated to prevent ponding and to be free draining.
Saaiplaas – Brand A Slimes Dam Complex	25 & 26	Regulation 7(a) – The trenches surrounding the Brand A Slimes Dam Complex that co nvey dirty water to Dam 13 are unlined. 	The Brand A Slimes Dam Complex is visible on aerial imagery that pre-dates June 1999 when GN R704 was enacted, and it is therefore likely that the trenches were in place. Exemption should be applied for.
Saaiplaas – No. 21/H3 Slimes Dam and D-Dam	27, 28 & 29	Regulation 7(a) – The trenches surrounding the No. 21/H3 Slimes Dam that convey dirty water to the D-Dam are unlined. The D-Dam is also unlined.	The No. 21/H3 Slimes Dam is visible on aerial imagery that pre-dates GN R704, and it is therefore likely that the trenches and the D-Dam were in place. Exemption should be applied for.

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
Saaiplaas – D-Dam	29	Regulation 8(a) – The D-Dam is not fenced-off and no warning signs were noted at prominent locations at the D-Dam. 	Due to the coarse resolution of old aerial imagery, it could not be ascertained whether the D-Dam pre-dates GN R704. It is recommended that warning signs are erected at prominent locations and that the dam is fenced-off to the public.
Saaiplaas – Plant	30, 31 & 32	Regulation 7(a) – The Saaiplaas No. 3 RWD, Video Evaporation Dams and No. 5 RWD are unlined.	The dams are visible on aerial imagery that pre-dates June 1999 when GN R704 was enacted. Exemption should be applied for.
Saaiplaas – Plant	30, 31 & 32	Regulation 8(a) – The Saaiplaas No. 3 RWD, Video Evaporation Dams and No. 5 RWD are not fenced-off and no warning signs were noted at prominent locations.	It is recommended that warning signs are erected at prominent locations and that the dams are fenced-off. It should be noted that the dams were constructed prior to June 1999 when GN R704 was enacted and may potentially be exempted on this basis.
Saaiplaas – Plant	33 – 37	Regulation 7(a) – The trench conveying dirty water from the Saaiplaas Plant to the No. 3 RWD is unlined. This is also the case for the trenches surrounding the Saaiplaas Slimes Dam Complex 1, 2, 3, 4, 5a, 5b and 6. 	The Saaiplaas Slimes Dam Complex 1, 2, 3, 4, 5a, 5b and 6 are visible on aerial imagery that pre-dates GN R704, and it is therefore likely that the trenches were in place. Exemption should be applied for.
Saaiplaas – Plant	38	Regulation 6(c) and 6(d) – A berm has been constructed around the Saaiplaas 2 Shaft WRD to contain runoff. The berm was noted to contain openings along the access roads and at various other locations. 	It is recommended that a ramp is constructed where berms have been opened for roads.
Saaiplaas – Saaiplaas 2 Shaft WRD	38	Regulation 5 – It appears that waste rock that may potentially be hazardous has been used in the construction of berms at the Saaiplaas 2 Shaft WRD. 	A waste classification (geochemical assessment) should be undertaken on the waste rock material. Should the waste classification indicate that the material is non-hazardous, then exemption from GN R704 should be applied for, for the use of waste rock in the construction of berms as well as for any other purposes at the mine (e.g. roads, embankments, dams, etc.). It should be noted that the WRD is visible on aerial imagery that pre-dates GN R704.
Saaiplaas – Saaiplaas 2 Shaft WRD	38	Regulation 7(a) – The Saaiplaas 2 Shaft WRD is unlined and may potentially seep hazardous water.	The Saaiplaas 2 Shaft WRD is visible on aerial imagery that pre-dates GN R704. Exemption should be applied for. Alternatively, a geochemical assessment should be undertaken to determine whether the waste rock is hazardous.

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
Saaiplaas – 3 Shaft WRD	39	Regulation 6(c), 6(d) and 7(a) – No measures to contain runoff from the Saaiplaas 3 Shaft WRD were noted. The Saaiplaas 3 Shaft WRD is unlined and may potentially seep hazardous water. 	A berm should be constructed around the WRD. The Saaiplaas 3 Shaft WRD is visible on aerial imagery that pre-dates GN R704. Exemption should be applied for. Alternatively, a geochemical assessment should be undertaken to determine whether the waste rock is hazardous.
Saaiplaas – Brand RWD	40	Regulation 7(a) – The Brand RWD is unlined and may potentially seep hazardous water.	The Brand A RWD is visible on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Saaiplaas – Brand RWD	40	Regulation 8(a) – The Brand RWD is not fenced-off.	It is recommended that the dam is fenced-off. It should be noted that the dam was constructed prior to June 1999 when GN R704 was enacted and may potentially be exempted on this basis.
Saaiplaas – WRDs	41 – 50	Regulation 6(c), 6(d) and 7(a) – All WRDs have berms around their perimeters except for the St Helena WRD, Brand 1 Shaft WRD 1 & 2 and St Helena 2 WRD which only have remnants of waste rock remaining. Many of the berms are disconnected and are generally open where roads have been constructed to access the WRDs. Some of the berms were noted to be constructed with waste rock. All of the WRDs are unlined and may potentially seep hazardous water.	It is recommended that a ramp is constructed where berms have been opened for road access to ensure that runoff is contained within the WRD footprint areas. A waste classification (geochemical assessment) should be undertaken on the waste rock material. Should the waste classification indicate that the material is non-hazardous, then exemption from GN R704 should be applied for, for the use of waste rock in the construction of berms as well as for any other purposes at the mine (e.g. roads, embankments, dams, etc.). All of WRDs are visible on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Saaiplaas – Slimes Dams	–	Regulation 7(a) – All of the Saaiplaas slimes dams are unlined and may potentially seep dirty water.	All of slimes dams are visible on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Saaiplaas – St Helena 1, 2, 3 and 4 Slimes Dam Complex	50, 51 & 55	Regulation 7(a) – The trenches conveying dirty water from the slimes dams to the RWDs are unlined.	The slimes dams are visible on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Saaiplaas – St Helena 4 RWD	54	Regulation 6(d), 7(a) & 8(a) – The St Helena 4 RWD was noted to be overflowing at the time of the site visit. The dam is also unlined and is not fenced-off and does not have any warning signs erected in prominent locations.	The water levels in the dam should be managed to ensure that there is always sufficient capacity available to contain the 50 year runoff. Warning signs in prominent locations should be erected and the dam should be fenced off to the public. The St Helena 4 RWD is visible on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Saaiplaas – St Helena 1, 2, 3 RWD and Stormwater Dam	52 & 53	Regulation 6(d) & 8(a) – The St Helena 1, 2, 3 RWD and Stormwater Dam were noted to be silted which compromises their capacity to contain the 50 year runoff. The dams are also not fenced-off to the public. 	The dams should be desilted (if possible). The water levels in the dams should be managed to ensure that there is always sufficient capacity available to contain the 50 year runoff. The dams should be fenced off to the public.
Saaiplaas – Underground mining	–	Regulation 4(b) – Underground mining is likely to have taken place beneath a watercourse.	Mining pre-dates GN R704. Exemption should be applied for.

6.4 Conceptual Stormwater Management Plan

The existing and proposed stormwater measures at the Saaiplaas Operations are shown on Figure 6-4 and Figure 6-5 and are described below.

6.4.1 Existing Stormwater Measures

6.4.1.1 Saaiplaas Plant

The Saaiplaas Plant consists of the following stormwater measures:

- The plant area is mostly concrete lined;
- Dirty areas where spills may occur, such as the Carbon-in-Leach (CIL) tank area, are bunded and report to sumps that pump back into the process;
- Lined dirty water channels DC3 and DC4, that capture and convey dirty runoff as well as overflows from the tanks (Barren Tanks and Mill Return Tanks) to the Saaiplaas No. 3 RWD;
- Silt trap ST1 which settles out silt from upslope runoff as well as to settle out silt when the Mill Return Tanks are drained;
- Lined dirty water channel/sump DC6, that captures spills and silt from the thickeners as well as runoff from the Wash Bay, which is pumped back into the thickeners;
- Lined dirty water channel DC8 that conveys water from the Mass Flow Area to Silt Trap ST1; and
- Unlined dirty water channel DC9 that conveys runoff from the Wood Chip Screening Area to channel DC8.

6.4.1.2 Brand A Slimes Dam Complex

The Brand A Slimes Dam Complex is currently being reclaimed and consists of the following stormwater measures:

- The slimes dam is surrounded by an unlined solution trench which captures seepage and runoff from the slimes dam and conveys it to Dam 13;
- The footprint of the slimes dam has been separated into paddocks to contain stormwater. Stormwater collected within the paddocks is slowly released from the paddocks into the surrounding solution trench; and
- High pressure water cannons are used to turn the tailings material into a slurry which flows to a pump station located on the south-western corner of the slimes dam. The pump station is bunded and consists of sumps and pumps that pump spills back into the process. Coarse material such as vegetation is also removed at the pump station and is contained within a concrete lined sump. Slurry from the pump station is pumped to the Saaiplaas Plant for processing.

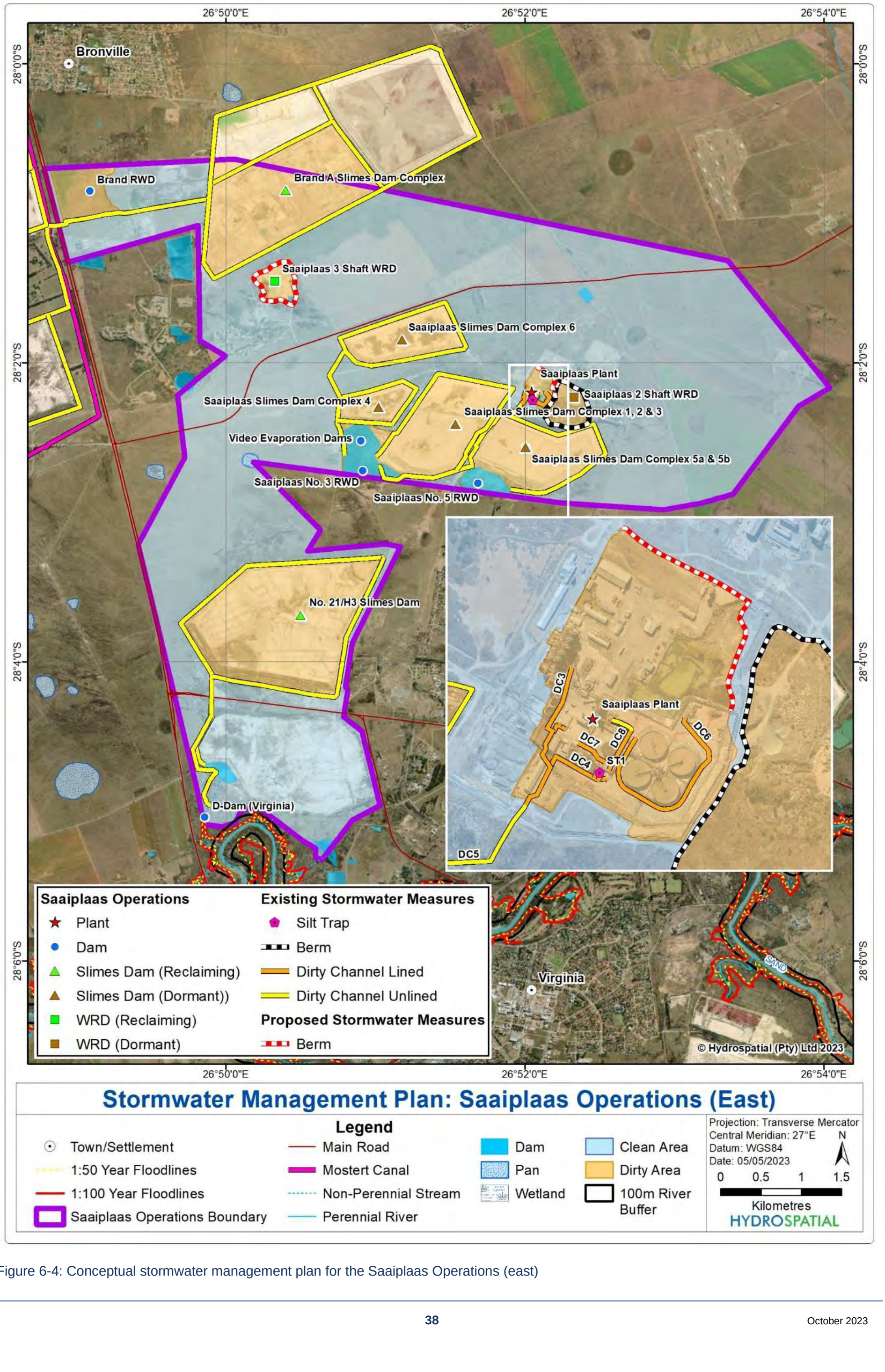


Figure 6-4: Conceptual stormwater management plan for the Saaiplaas Operations (east)

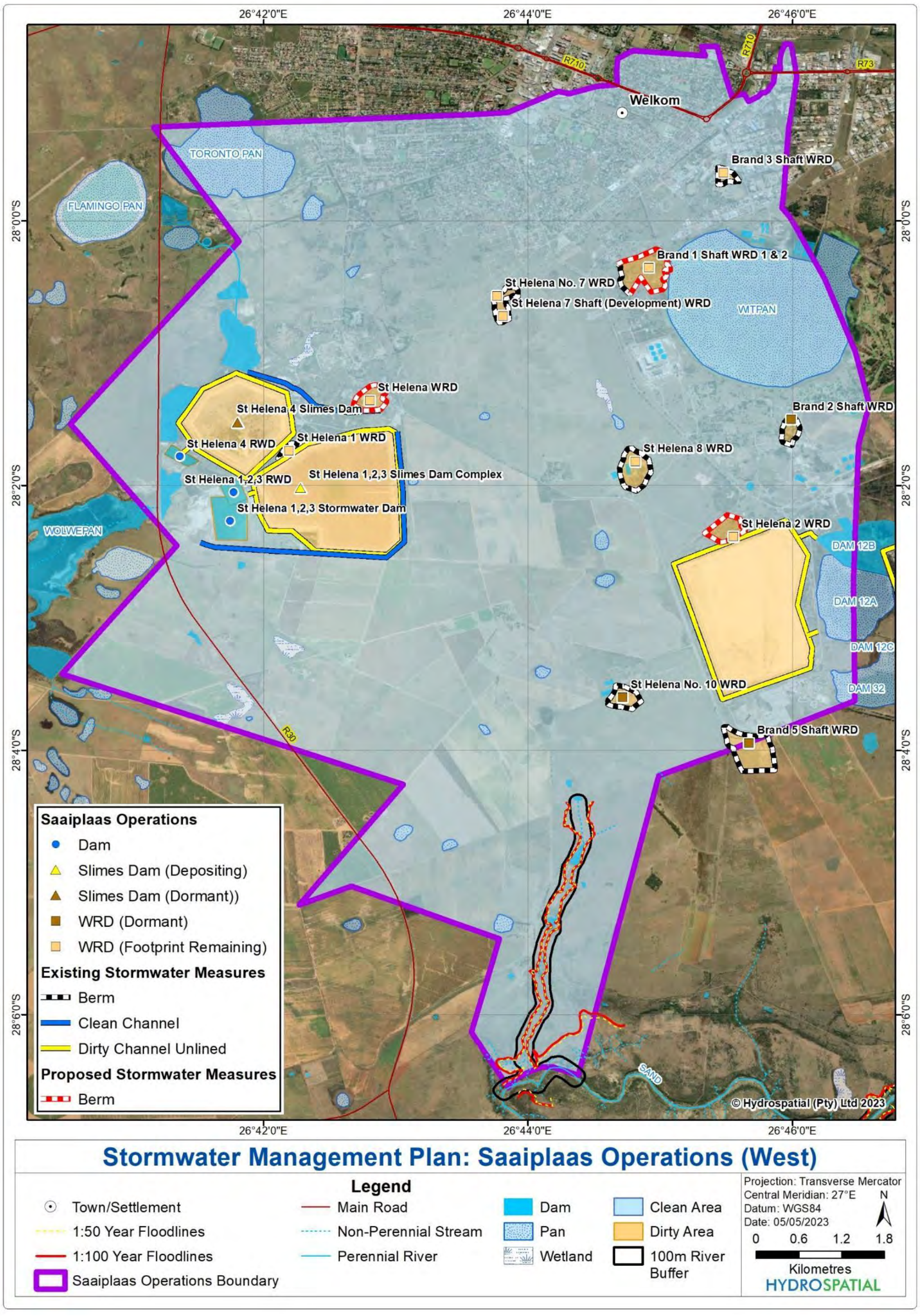


Figure 6-5: Conceptual stormwater management plan for the Saaiplaas Operations (west)

6.4.1.3 No. 21/H3 Slimes Dam

The No. 21/H3 Slimes Dam is currently being reclaimed and consists of the following stormwater measures:

- The slimes dam is surrounded by an unlined solution trench which captures seepage and runoff from the slimes dam and conveys it to the D-Dam (Virginia);
- The footprint of the slimes dam has been separated into paddocks to contain stormwater. Stormwater collected within the paddocks is slowly released from the paddocks into the surrounding solution trench; and
- High pressure water cannons are used to turn the tailings material into a slurry which flows to a pump station located on the south-eastern corner of the slimes dam. The pump station is bunded and consists of sumps and pumps that pump spills back into the process. Coarse material such as vegetation is also removed at the pump station and is contained within a concrete lined sump. Slurry from the pump station is pumped to the Saaiplaas Plant for processing.

6.4.1.4 St Helena 1, 2, 3 Slimes Dam Complex

Tailings produced at the Saaiplaas Plant is deposited on the St Helena 1, 2, 3 Slimes Dam Complex which consists of the following stormwater measures:

- Clean water channels to divert upslope runoff around the slimes dam;
- Unlined perimeter toe paddocks and solution trench to capture seepage and runoff from the slimes dam and to convey it to the St Helena 1, 2, 3 RWD and Stormwater Dam; and
- The St Helena 1, 2, 3 RWD and Stormwater Dam are lined facilities.

6.4.1.5 Other Slimes Dams

The other slimes dams which include the St Helena 4 Slimes Dam as well as the Saaiplaas 1, 2, 3, 4, 5a, 5b and 6 Slimes Dam Complexes are all dormant. These slimes dams all consist of unlined solution trenches along their perimeters. Runoff and seepage from the St Helena 4 Slimes Dam reports to the unlined St Helena 4 RWD, whilst Saaiplaas 1, 2, 3, 4, 5a, 5b and 6 Slimes Dam Complexes report to the unlined Saaiplaas No. 3 RWD. The eastern side of the Saaiplaas 5a and 5b Slimes Dam Complex reports to the unlined Saaiplaas No. 5 RWD.

6.4.1.6 Waste Rock Dumps

The Saaiplaas 2 Shaft WRD, Brand 2 Shaft WRD, Brand 3 Shaft WRD, Brand 5 Shaft WRD, St Helena 1 WRD, St Helena No. 7 WRD, St Helena 8 WRD and St Helena No.10 WRD, all contain berms around their perimeters to contain runoff. Many of these berms are disconnected and are generally open where roads have been constructed to access the WRDs. In many cases it appears that waste rock has been used in the construction of the berms.

The St Helena WRD, Brand 1 Shaft WRD 1 & 2 and St Helena 2 WRD only have their footprints remaining and do not contain perimeter berms, however, remnants of waste rock were noted

at these facilities. No berm was observed around the Saaiplaas 3 Shaft WRD which is currently being reclaimed for aggregate.

6.4.2 Clean and Dirty Areas

The dirty areas at the Saaiplaas Operations include the plant, slimes dams, WRDs, RWDs and stormwater dams. Dirty areas should be contained to ensure that they do not flow or seep into clean areas. The remaining areas should be managed as clean areas, which should not be contaminated by dirty areas, or flow into dirty areas. Figure 6-4 and Figure 6-5 shows the clean and dirty areas at the Saaiplaas Operations.

6.4.3 Proposed Stormwater Measures and Recommendations

The following are proposed stormwater measures and recommendations for the Saaiplaas Operations:

- The channels, silt traps and sumps at the Plant should be inspected at least on a monthly basis for sediment build up and should be cleaned more frequently than is currently done;
- A berm is constructed upslope of the plant on the northern and north-eastern side, to divert clean water around the plant;
- It is recommended that a concrete ramp is erected at the entrance of the Wash Bay at the Plant to contain runoff from this facility;
- Stockpiling of potentially hazardous material such as wood chips should take place on a lined and contained area at the Plant;
- Runoff from the Wood Chip Screening Area at the Plant contains high suspended solids which results in channel DC8 and Silt Trap ST1 being silted up regularly. It is recommended that either a sediment screen, sump or silt trap is investigated immediately below the Wood Chip Screening Area. It is further recommended that the channel from the Wood Chip Screening Area is lined; and
- The removal of infrastructure at the old milling area at the Plant has created a depression which results in the ponding of water. This area should be rehabilitated to be free draining;
- The water levels of the RWDs and stormwater dams are inspected on a regular basis to ensure that there is always sufficient capacity to contain the 50 year runoff;
- A berm is proposed around the Saaiplaas 3 Shaft WRD, St Helena WRD, Brand 1 Shaft WRD 1 & 2 and St Helena 2 WRD;
- All sump pumps should be installed with automatic water level sensors to ensure that the sumps or bunded areas do not overflow;
- Where the berms surrounding the WRDs have been opened for road access, it is proposed that ramps are built across the roads so that runoff is contained within the footprint area of the WRDs; and
- The recommendations provided in Table 6-3 should be implemented.

7 TARGET OPERATIONS

7.1 Description of Operations

The infrastructure that forms part of the Target Operations is shown on Figure 7-1. Underground mining was initiated in 1950 and the Target Operations have an approximate LoM until 2027. Ore is hoisted to surface at the Target 1 Shaft and the depths of the underground workings are approximately 2 500 m below ground level. Operations at Target 2 Shaft ceased during 2009 and the underground workings have been flooded. Operations at Target 3 Shaft ceased in September 2014 and the shaft is currently under care and maintenance. This shaft continues to pump water from the underground workings to maintain safe operations at Target 1 Shaft, as these two shafts are connected via their underground workings. The Target Plant is situated south of the Target 1 Shaft, where mined ore and waste rock from the WRDs is processed. Tailings from the plant is deposited on the Target 1 and 2 Tailings Storage Facility (TSF) complex. Table 7-1 provides a summary of the current activities undertaken at the Target Operations and has been modified from SRK (2020e).

Table 7-1: Summary of activities undertaken at the Target Operation

Aspect	Method/System
Mining	
Underground mining	• There are six shafts at the Target Operations, one is operational and five are dormant: - Mining is undertaken at Target 1 Shaft at the ore body known as Eldorado Fan. - Target 2 and 3, and Freddie's 3, 6 and 9 shafts are dormant. • Mining depths are currently at approximately 2 500 m.
Beneficiation	
Metallurgy plants	• Mined ore is processed at the Target Plant. • Gold is smelted at the Target Plant. • Tailings from the plant are deposited on the Target 1 and 2 TSF.
Water and waste management systems	
Water supply	The Target Operations receive water supply from Sedibeng Water, which is used for domestic purposes, and supplements for mining and metallurgical purposes.
Dirty (waste) water containment and release	• Dirty water (process water) is contained in process water dams and stormwater dams. • Dirty water runoff from the shafts and processing areas is contained in the dirty water containment facilities, including RWDs. • Water from the dirty water containment facilities including the RWDs is reused in the process.
Clean water diversions	Clean water diversions are in place at the shafts and processing areas to direct runoff from the surrounding catchment, away from the dirty areas.
Waste rock	Waste rock from the shafts is sent to the Lorraine 1 New and Old WRDs, the Lorraine 2 WRD and the Freddie's WRD. Waste rock from these WRDs is reclaimed and sent to the Target Plant to be processed.

Aspect	Method/System
Tailings	• Tailings are transported via pipeline to the Target 1 and 2 TSF. • The Target 1 and 2 TSF will continue to receive tailings until the design life of each facility.
Domestic and industrial waste	Standard operating procedures have been developed for waste management at theTarget Operations. • Domestic waste generated at the Target Operations is taken off-site to aregistered landfill site. • Industrial waste is handled at the shaft and processing areas in designated wasteareas. Scrap metal, wood and plastic are recycled through the Salvage Yard. • Hazardous waste is handled by the appointed contractor, currently Micro Trading,and is transported off-site to a registered hazardous waste facility.
Sewage	• Sewage from the Target Operations, except Target 3 Shaft, is directed to the municipal sewage treatment works. • Sewage effluent at the Target 3 Shaft is handled at the Target 3 SewageTreatment Plant (STP). • Treated sewage effluent is recycled in the process.
Support infrastructure	
General infrastructure	The support infrastructure associated with the Target Operations includes: • Administration offices • Change houses • Engineering workshops • Salvage yard.

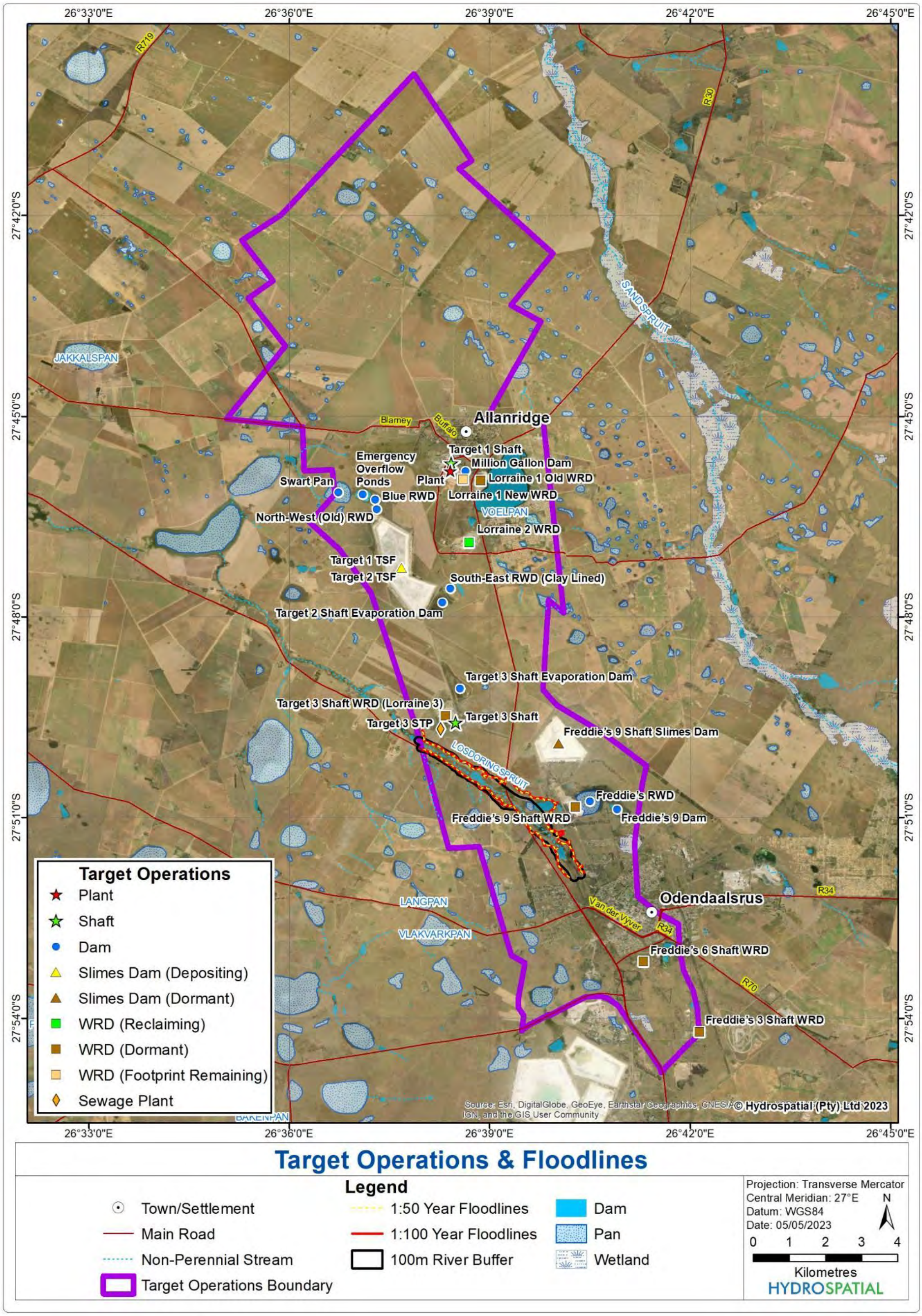


Figure 7-1: Target Operations and floodlines

7.2 Floodlines

A non-perennial stream known as the Losdoringspruit, flows in a north-westerly direction immediately to the south of the Target 3 Shaft. The floodlines and 100 m buffer have been determined for this stream. A summary of the estimated peak flows that were used to determine the floodlines is provided in Table 7-2, whilst the floodlines and 100 m stream buffer is shown on Figure 7-1.

Table 7-2: Peak flows used to determine the floodlines for the Target Operations

River	Catchment Area (km^2)	Method	1:50 Year Peak Flow (m^3/s)	1:100 Year Peak Flow (m^3/s)
Losdoringspruit	106.10	Rational	131	172
		SCS	145	180
		Midgley & Pitman	139	176
		Average	**138**	**176**

- No mine infrastructure is located within the floodlines or within 100 m of a river, however, the following infrastructure is located within 100 m of a dam or pan:
  - Lorraine 1 Old WRD; and
  - Freddie's 9 Shaft WRD.

7.3 GN R704 Audit

Figure 7-2 to Figure 7-4 indicates the location of the non-compliances with GN R704, whilst Table 7-3 provides a summary of the non-compliances and recommendations for improvement at the Target Operations.

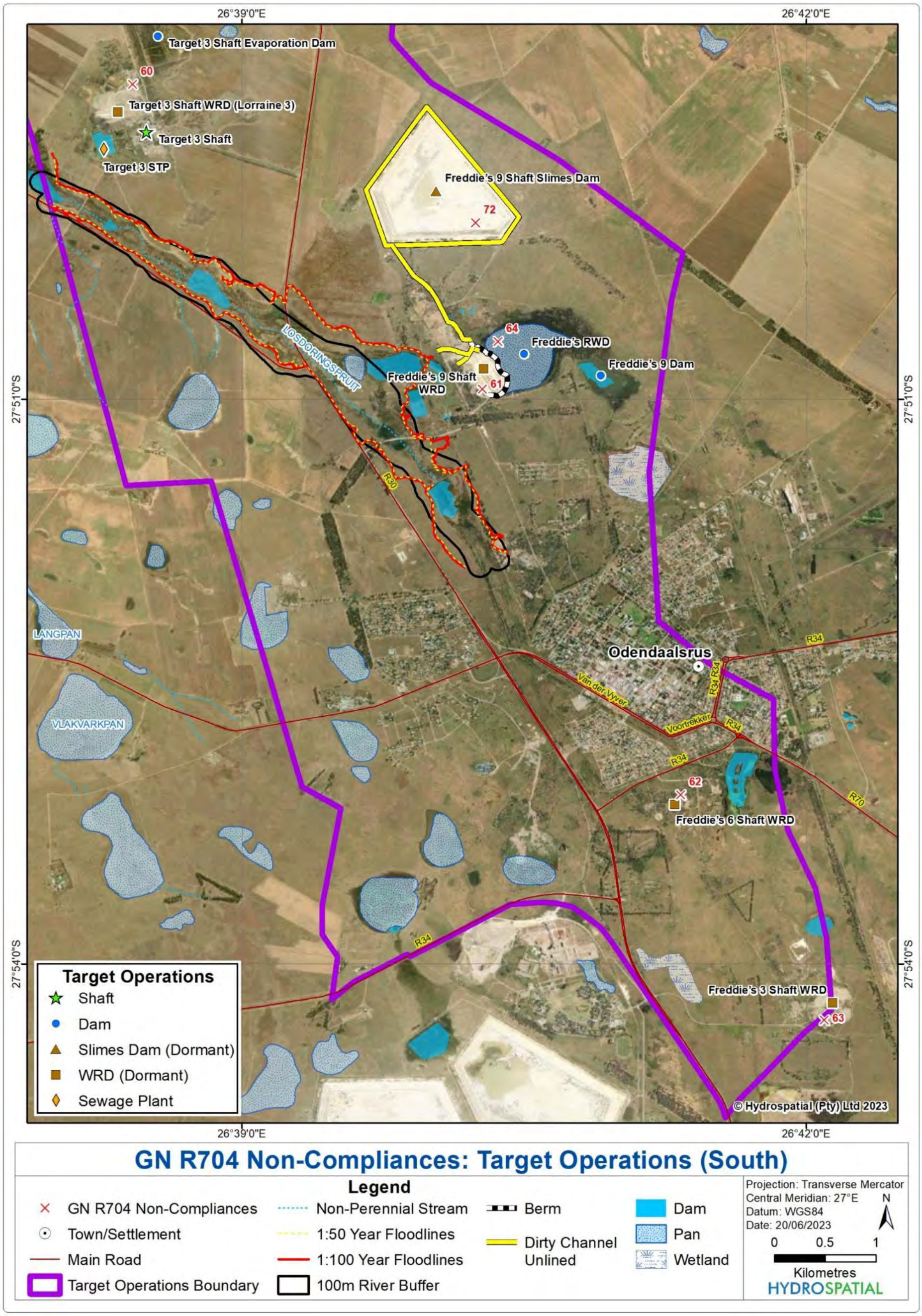


Figure 7-2: Location of the GN R704 non-compliances at the Target Operations (south)

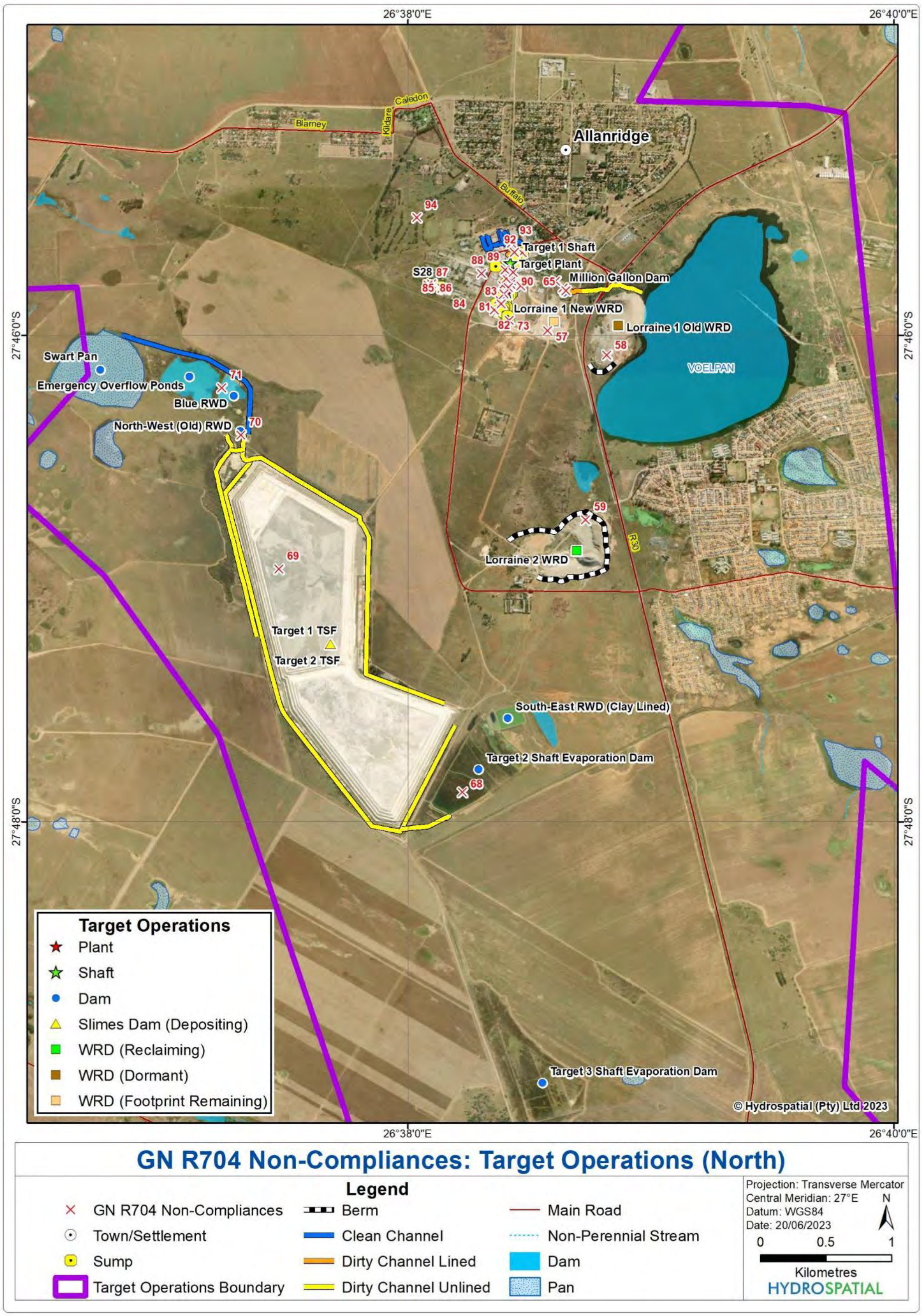


Figure 7-3: Location of the GN R704 non-compliances at the Target Operations (north)

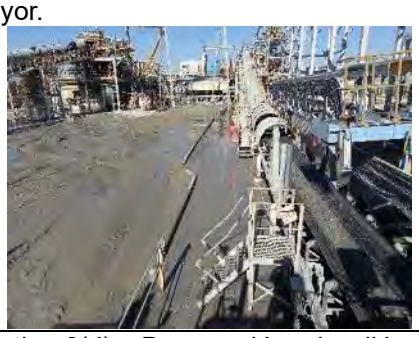


Figure 7-4: Location of the GN R704 non-compliances at the Target Plant and 1 Shaft

Table 7-3: Target Operations GN R704 non-compliances and recommendations

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
Target – WRDs	57-63	Regulation 6(c) & 6(d) – The Target 3 Shaft WRD, Freddie's 6 Shaft WRD and Freddie's 3 Shaft WRD do not have berms around their perimeters and are therefore uncontained. The Lorraine 1 Old WRD, Lorraine 2 WRD and Freddie's 9 Shaft WRD, have berms around them but there are sections where the berms are disconnected, such as where roads have been constructed. The Lorraine 1 New WRD has been reclaimed, however, there are still remnants of waste rock remaining. Regulation 7(a) – All of the WRDs are unlined and may potentially seep hazardous water. Regulation 5 – Some of the berms around the WRDs were noted to be constructed with waste rock which may potentially be hazardous.	It is recommended that a ramp is constructed where berms have been opened for road access to ensure that runoff is contained within the WRD footprint areas. A waste classification (geochemical assessment) should be undertaken on the waste rock material. Should the waste classification indicate that the material is non-hazardous, then exemption from GN R704 should be applied for, for the use of waste rock in the construction of berms as well as for any other purposes at the mine (e.g. roads, embankments, dams, etc.). All of WRDs are visible on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Target – WRDs	58 & 61	Regulation 4(a) – The Lorraine 1 New WRD and Freddie's 9 Shaft WRD have been constructed within 100 m of a pan or dam.	The WRDs are visible on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Target – Freddie's RWD	64	Regulation 6(c), 6(d) & 7(a) – Dirty water from the Freddie's RWD overflows via a channel through the Freddie's 9 Shaft WRD into a non-perennial stream to the west.	Rainfall in excess of 800 mm was received over the 2021/2022 rainy season, which is almost double the mean annual rainfall for the area. This in combination with a leaking municipal pipeline, resulted in high water levels which most likely lead to Freddie's RWD overflowing. It is further likely that Freddie's RWD seeps towards the non-perennial stream to the west, as it is an unlined facility. Both Freddie's RWD and Freddie's 9 Shaft WRD are visible on aerial imagery that pre-dates GN R704.
Target – Million Gallon Dam	65	Regulation 6(c), 6(d) & 7(a) – The Million Gallon Dam receives excess groundwater from the Target 1 Shaft and returns it to the Target Plant for use. This dam was noted to be overflowing towards Voelpan which is an unlined facility. This appears to be a common occurrence. It is understood that Voelpan was used in the past to store excess water from the Target Operations. The concrete lined channel from the Million Gallon Dam to Voelpan was noted to be damaged and therefore likely to seep dirty water. 	The Million Gallon Dam should as far as possible be prevented from spilling. In addition, if Voelpan was used prior to 1999 for the storage of excess groundwater from the Target Operations, and this was done in agreement with the DWS, then exemption from GN R704 should be applied for. The concrete channel from the Million Gallon Dam to Voelpan should be repaired.
Target – Million Gallon Dam	66	Regulation 6(c), 6(d) & 7(a) – The evaporators along the sides of the Million Gallon Dam were noted to be spraying dirty water onto natural ground. 	The spray from the evaporators should be directed as far as possible towards the centre of the dam.
Target – Million Gallon Dam	67	Regulation 6(c), 6(d) & 7(a) – The pipeline conveying dirty water to the Million Gallon Dam was noted to be leaking. 	The pipeline should be regularly inspected and leaks must be repaired immediately.

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
Target – Target 2 Shaft Evaporation Dams	68	Regulation 8(a) – No warning signs in prominent locations were noted at the Target 2 Shaft Evaporation Dams. Furthermore, the dams are not fenced-off to the public. 	It is recommended that warning signs are erected at prominent locations and that the dams are fenced-off. It should be noted that the dams were constructed prior to June 1999 when GN R704 was enacted and may potentially be exempted on this basis.
Target – Target 1 and 2 TSFs	69	Regulation 7(a) – The Target 1 and 2 TSFs as well as the perimeter solution trenches are unlined and may seep dirty water.	The TSFs are visible on aerial imagery that pre-dates June 1999 when GN R704 was enacted. Exemption should be applied for.
Target – North-West (Old) RWD	70	Regulation 6(d) – The North-West (Old) RWD, also known as the Plastic Dam, was noted to be heavily silted, which compromises its capacity. 	The dam should be desilted on a more regular basis.
Target – Blue RWD and Emergency Overflow Ponds	71	Regulation 6(d) – These dams were noted to be silted, compromising their capacity. 	The dams should be desilted on a more regular basis.
Target – Freddies 9 Shaft Slimes Dam	72	Regulation 7(a) – The Freddies 9 Shaft Slimes Dam as well as the perimeter solution trenches are unlined and may seep dirty water.	The slimes dam is visible on aerial imagery that pre-dates June 1999 when GN R704 was enacted. Exemption should be applied for.
Target – Plant	73	Regulation 6(d) – The sump has the potential to overflow due to rainfall entering the sump. 	A roof should be constructed over the sump.
Target – Plant	74	Regulation 6(c), 6(d) & 7(a) – Ponding of water towards the north-east of the plant most likely due to the Raw Water Tanks overflowing. The Raw Water Tanks receive water from the Target TSFs.	The water levels of the Raw Water Tanks should be monitored and managed so that spills do not occur. In addition, it is proposed that a sump that captures and pumps dirty water back into the process is investigated in the north-eastern corner of the plant, to deal with the ponding issues that occur here.
Target – Plant	75	Regulation 6(c), 6(d) & 7(a) – The stockpiling of potentially hazardous material such as waste rock and silt from clean-ups, does not take place on a lined and contained areas at the Target Plant. 	It is assumed that the material stockpiled at the Target Plant is hazardous as a waste classification (geochemical assessment) was not available. It is recommended that a waste classification is undertaken to determine whether the material is hazardous and needs to be stockpiled on lined areas.
Target – Plant	76	Regulation 6(d) – The sumps in general at the Target Plant were noted to be silted which compromises their capacity.	The sumps should be cleaned on a more frequent basis than is currently being done at the Target Plant.

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
			
Target – Plant	77	Regulation 6(c), 6(d) & 7(a) – An unlined informal channel drains the western side of the Target Plant and reports to a lined channel. 	It is proposed that the channel is formalised and lined.
Target – Plant	78	Regulation 6(c) & 6(d) – The western side of the Target Plant drains to the north-western corner and ponds in this area.	A dirty water containment facility in the form of a PCD is proposed in the north-western corner of the plant.
Target – Plant	79	Regulation 6(c), 6(d) & 7(a) – The bunded areas below the silo, milling area and conveyors at the plant were silted and overflowing at the time of the site visit. The area between the two conveyors is unlined. A broken bund wall was also noted below the conveyor. 	The bunded areas at the plant should be inspected and cleaned more frequently than weekly. It is recommended that inspections are undertaken daily. Should the area between the two conveyors frequently receive silt, then it is proposed that this area is lined. The broken bund below the conveyor should be repaired.
Target – Plant	80	Regulation 6(d) – Damaged bund wall leading to spills. 	The damaged bund wall should be repaired. This should be done for all damaged bund walls at the plant.
Target – Plant	81	Regulation 6(c), 6(d) & 7(a) – Spill from the Absorption Tanks on an unlined area. 	The Absorption Tanks should be monitored to ensure that they do not spill.
Target – Plant	82	Regulation 6(d) – The bunded area at the Leach Tanks was silted. 	As mentioned previously, the bunded areas at the Target Plant should be inspected and cleaned more frequently than weekly. It is recommended that inspections are undertaken daily.
Target – Plant	83	Regulation 6(d) – The channel between the Absorption Tanks and Thickeners was covered in mud and blocked.	The channels at the plant should be inspected daily and cleared of mud and silt as soon as possible.

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
			
Target – 1 Shaft	84	Regulation 6(c), 6(d) & 7(a) – Hydrocarbon spills on unlined areas. 	The storage of hazardous materials must take place on a lined and contained area.
Target – 1 Shaft	85	Regulation 6(c), 6(d) & 7(a) – The channels and concrete lined area at the sorting area are old and cracked and may seep hazardous substances. 	Repair concrete lined area and channels at the sorting area.
Target – 1 Shaft	86	Regulation 6(c), 6(d) & 7(a) – The Salvage Yard Evaporation Dam was noted to be seeping from the side wall. In addition to this, spills were noted at the oil skimmer. 	The side walls of the Evaporation Dam should be sealed to prevent seepage. Oil skimming should be done over a lined and contained facility.
Target – 1 Shaft	87	Regulation 6(c), 6(d) & 7(a) – The channels at the Wash Bay were silted with debris. 	The channels should be regularly inspected and cleared of debris.
Target – 1 Shaft	88	Regulation 6(c), 6(d) & 7(a) – A gap in the bund wall at the chemical store can lead to spills. 	Seal the gap in the bund wall.
Target – 1 Shaft	89	Regulation 5 – Tailings is mixed with a binder at the Backfill Plant and is used to backfill the underground workings. The tailings material may potentially be hazardous.	No geochemical assessment or waste classification has been undertaken on the tailings material and therefore the tailings is assumed to be hazardous. It is recommended that a geochemical assessment is undertaken. Furthermore, an exemption from GN R704 for the backfilling of the underground workings with tailings material is required.
Target – 1 Shaft	90	Regulation 6(c), 6(d) & 7(a) – The stockpiling of potentially hazardous material at the Ore Receiving Area does not take place on a lined and contained areas.	It is assumed that the material is hazardous as a waste classification (geochemical assessment) was not available. It is recommended that a waste classification is undertaken to determine

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
			whether the material is hazardous and needs to be stockpiled on lined areas.
Target – 1 Shaft	91	Regulation 6(d) – The trench between Sump 30 and 31 is blocked.	The trench should be cleared of debris.
Target – 1 Shaft	92	Regulation 6(c) – Overflow from the dirty channels at the workshops flows into the clean stormwater network which conveys water to Voelpan.	The dirty water channels at the workshops should not be connected to the clean stormwater channels.
Target – 1 Shaft	93	Regulation 6(c) – Dirty water from the change houses should not report to the clean stormwater network.	Harmony is proposing to construct Sump S33 to capture dirty water from the change houses. This sump will pump to Dam D3. It is recommended that this is undertaken.
Target – 1 Shaft	94	Regulation 7(a) & 8(a) – Dirty water from the Million Gallon Dam is pumped to the Mine Club Dam. This dam is not lined and is not fenced-off to the public. Furthermore, no warning signs are in place.	It is not clear on historical aerial imagery whether this dam was constructed prior to GN R704. The dam should be lined if it stores dirty water. The dam should be fenced off to the public and warning signs should be erected.

7.4 Conceptual Stormwater Management Plan

The existing and proposed stormwater measures at the Target Operations are shown on Figure 7-5 to Figure 7-7 and are described below. The Target 3 Shaft was not assessed as it is closed and under care and maintenance, and no dirty water is currently generated at the 3 Shaft.

7.4.1 Existing Stormwater Measures

The following are existing stormwater measures at the Target Operations.

7.4.1.1 Target Plant

- The processing areas at the Target Plant are concrete lined and bunded and report to sumps that pump dirty water back into the process,
- Sump S6 captures runoff from the Paint and Oil Stores, whilst as discussed above, the remainder of the sumps are situated in processing area of the plant; and
- Dirty channel DC11 is situated in the north-western corner of the plant. This channel does not report to any containment facilities.

7.4.1.2 Target 1 Shaft

- The Sumps S30 and S31 capture dirty runoff from the workshops and Sump S31 pumps to dirty channel DC13;
- A pump is installed on channel DC13 which pumps to a new cement dam D3. Dam D3 pumps to a new dam D2 at the Salvage Yard. Overflows from channel DC13 reports to the clean stormwater network to the north, which flows to Voelpan;
- Channel DC13 also drains the Winder House to the west as well as the shaft area to the south;
- Dirty water from the Fridge Plant drains to Sump S29;
- Sump S27 at the Salvage Yard receives dirty runoff from a hydrocarbon storage area;
- Sump S28 receives dirty runoff from the Wash Bay which pumps to the Salvage Yard Evaporation Dam;
- Overflows from the Million Gallon Dam reports to Voelpan via a lined and unlined channel; and
- The clean channels to the north of the Target 1 Shaft drain runoff from the Change Houses, which flows to Voelpan.

7.4.1.3 Waste Rock Dumps

The existing stormwater measures at the WRDs include berms around the Lorraine 1 Old WRD, Lorraine 2 WRD and Freddie's 9 Shaft WRD, however, there are sections where the berms are disconnected, such as where roads have been constructed to access the dumps. The Target 3 Shaft WRD, Freddie's 6 Shaft WRD and Freddie's 3 Shaft WRD do not have berms around their perimeters and are therefore uncontained. The Lorraine 1 New WRD has been reclaimed, however, there are still remnants of waste rock remaining.

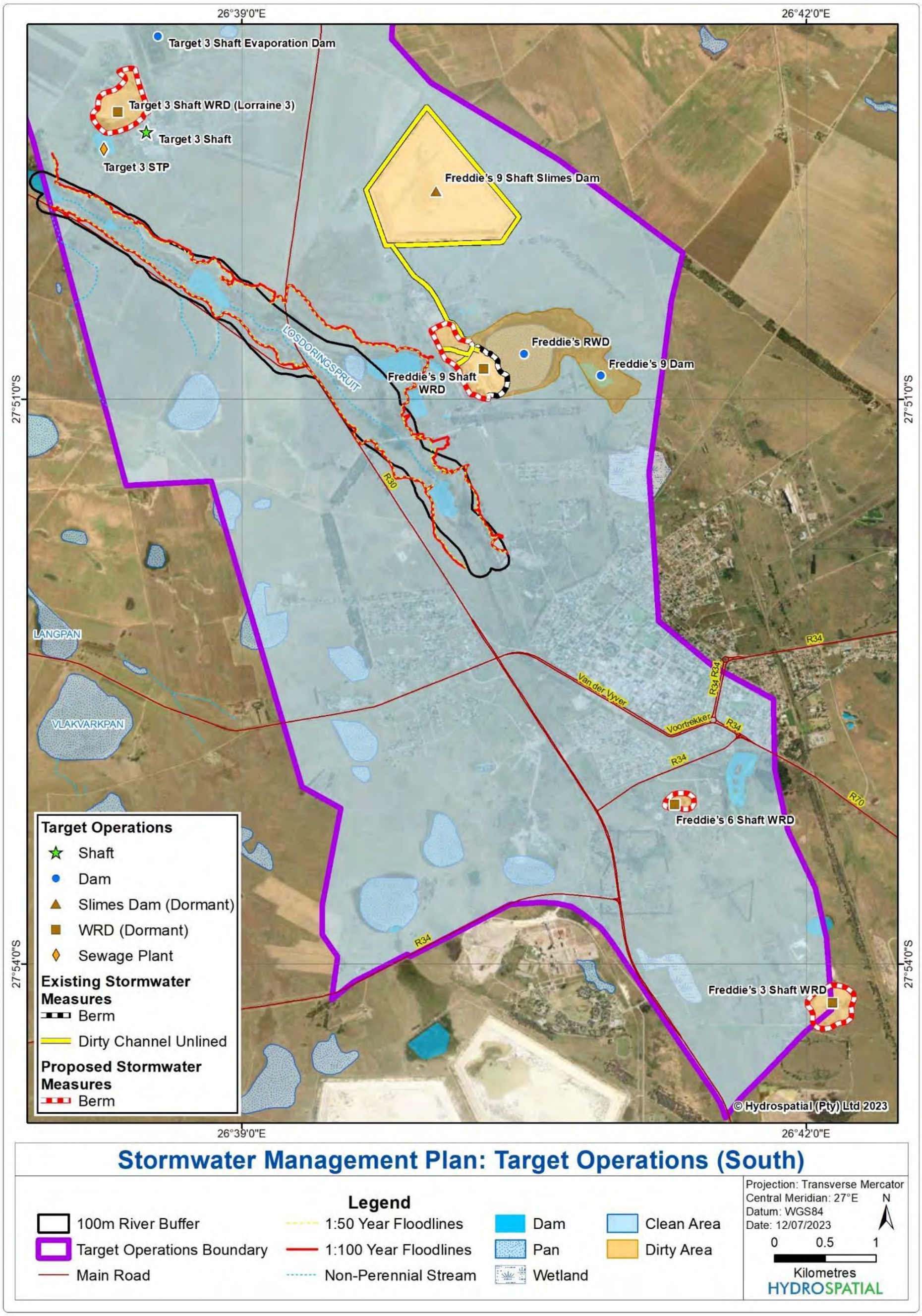


Figure 7-5: Conceptual stormwater management plan for the Target Operations (south)

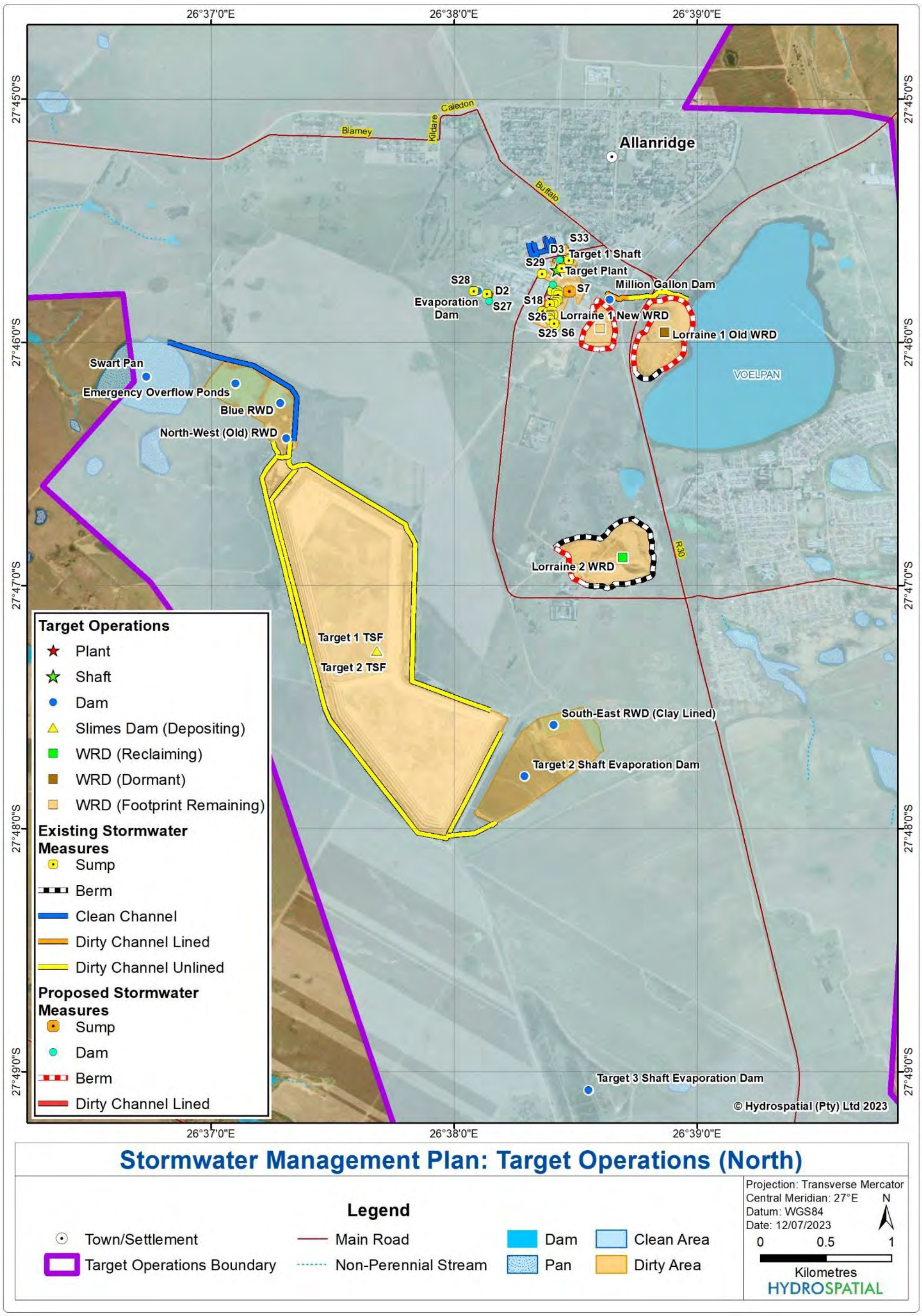


Figure 7-6: Conceptual stormwater management plan for the Target Operations (north)

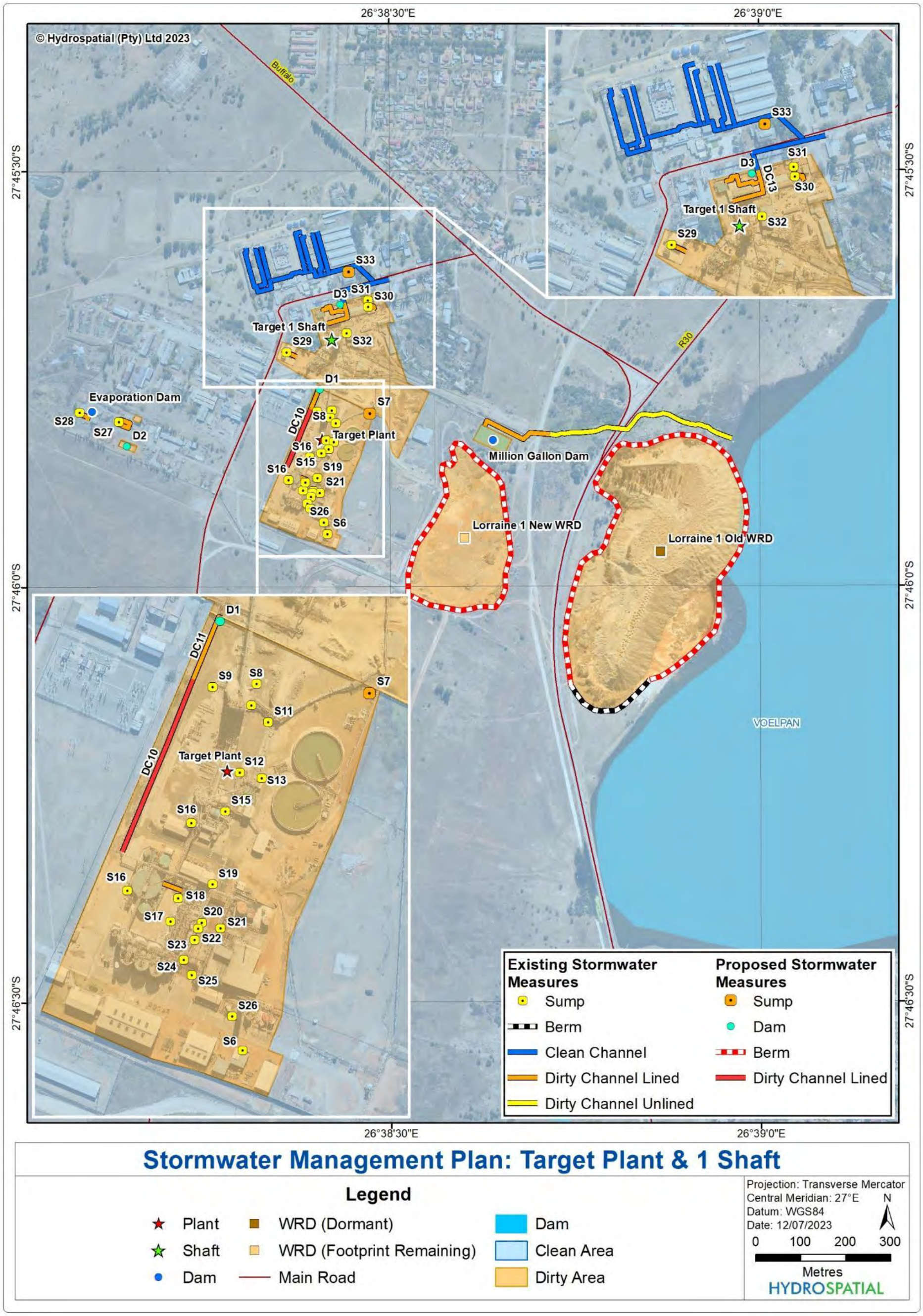


Figure 7-7: Conceptual stormwater management plan for the Target Plant and 1 Shaft

7.4.1.4 Slimes Dams

Unlined trenches have been constructed around the Target 1 and 2 TSFs as well as the Freddies 9 Shaft Slimes Dam.

7.4.1.5 Other Areas

A clean water channel has been constructed upslope of the North West RWD, Blue RWD and Emergency Overflow Ponds. This channel diverts runoff around these facilities to Swart Pan.

7.4.2 Clean and Dirty Areas

The dirty areas at the Target Operations include the TSFs / Slimes Dams, WRDs, RWDs, evaporation dams, plant and sections of the shaft. Dirty areas should be contained to ensure that they do not flow or seep into clean areas. The remaining areas should be managed as clean areas, which should not be contaminated by dirty areas, or flow into dirty areas. Figure 7-5 to Figure 7-7 show the clean and dirty areas at the Target Operations.

7.4.3 Proposed Stormwater Measures and Recommendations

The following are proposed stormwater measures and recommendations for the Target Operations:

7.4.3.1 Target Plant

- A roof should be constructed over Sump S6 as this sump can overflow due to rainfall entering it;
- A containment facility such as a sump (Sump S7) is proposed in the north-eastern corner of the Target Plant, to deal with ponding in this area. Dirty water captured in the sump should report back into the process;
- Areas used for the stockpiling of potentially hazardous material (e.g. waste rock) should be lined and contained;
- A formal lined channel DC10 is proposed on the western side of the plant;
- PCD D1 is proposed in the north-western corner of the plant, to capture and contain dirty runoff from channel DC10; and
- The build-up of silt at the plant appeared to be a major issue. It is recommended that the bunded areas, channels and sumps are inspected on a daily basis and cleaned more frequently than weekly.

7.4.3.2 Target 1 Shaft

- Dirty water dam D2 at the Salvage Yard was in the process of being constructed at the time of the site visit. This dam is planned to store excess underground water as well as dirty water from the shaft workshops. The dam should be included in the WULA;
- Dirty water dam D3 at the workshops was in the process of being constructed at the time of the site visit. Dirty water from Sump 30 and 31 will be pumped into channel DC13 which will then be pumped to D3. Dam D3 will pump to dam D2 at the Salvage Yard; and

- Harmony proposes to construct Sump S33, which will collect dirty water from the change houses and to pump to dam D3.

7.4.3.3 Waste Rock Dumps

- Berms that fully surround the WRDs should be constructed to capture and contain runoff and sediment.

7.4.3.4 Other Areas

- The channel from Freddie's 9 Shaft Slimes Dam to Freddie's RWD needs to be desilted.

In addition to the above, the recommendations provided in Table 7-3 should be implemented.

8 CENTRAL OPERATIONS

8.1 Description of Operations

The infrastructure that forms part of the Central Operations is shown on Figure 8-1. It should be noted that the boundary of the Central Operations overlaps with the Saaiplaas and Harmony 1 Operations. According to SRK (2020a), mining at the Central Operations was initiated in 1950, with the Central Plant being commissioned in September 1986. No underground mining is currently undertaken at the Central Operations and only reclaimed tailings, old plant clean-ups, environmental clean-ups and previously waste rock are processed at the Central plant. Re-pulped tailings from FSS5 Slimes Dam is pumped to the Central Plant for processing as part of the Phoenix Project. The No. 22 (H1) Slimes Dam has been reclaimed and only the footprint remains. The Central Operations mainly process the following:

- Reclamation of ARM 2, Masimong 4 and Masimong 5 WRDs which are delivered by rail. Currently no waste rock is being processed at the Central Plant;
- Re-pulped tailings from the hydraulic re-mining of FSS5 Slimes Dam which is delivered by pipeline;
- Carbon from the Saaiplaas and Joel Plants which is delivered by road; and
- Ad hoc environmental clean-ups which are delivered by road or rail.

Residue from the treatment process at the Central Plant is deposited on the No. 23 (H4) Slimes Dam Complex, as well as the Brand D Slimes Dam Complex. The Central Operations has an approximate LoM up to 2035.

A summary of the activities undertaken at the Central Operations is provided in Table 8-1 and was adapted from SRK (2020a).

Table 8-1: Summary of activities undertaken at the Central Operations

Aspect	Method/System
Mining	
Underground mining	• All four shafts at the Central Operations are dormant. These shafts are Merriespruit 1 and 3 shafts, and Virginia 1 and 2 shafts. • Activity at the dormant shafts is limited to recovery of waste rock for processing at the plant.
Beneficiation	
Metallurgy plants	• Re-pulped tailings from the hydraulic re-mining of the FSS5 Slimes Dam is processed at the Central Plant. • Gold is sent to the central smelt house at the Rand Refinery for smelting.
Water and waste management systems	
Water supply	The Central Operations receive water supply from Sedibeng Water, which is used for domestic purposes, and supplements mining and metallurgical purposes.
Dirty (waste) water containment and release	• Dirty water (process water) is contained in process water dams and stormwater dams. • Dirty water runoff from the shaft and processing areas is contained in the dirty water containment facilities, including the return water dams. • Water from the dirty water containment facilities including the return water dams is reused in the process.
Clean water diversions	Clean water diversions are in place at the shaft and processing areas to direct runoff from the surrounding catchment, away from the dirty areas.
Waste rock	The Merriespruit 1 Shaft, Merriespruit 3 Shaft, Virginia 1 Shaft and Virginia 2 Shaft waste rock dumps form part of the Central Operations, however no waste rock is currently being deposited at these facilities.
Tailings	• Tailings are transported via pipeline to the No 23 (H4) Slimes Dam Complex (Central Slimes Dam) and Brand D Slimes Dam Complex for deposition. • The Central Slimes Dam and Brand D Slimes Dam Complex will continue to receive tailings until 2035. • No tailings are currently being disposed on Calcine Slimes Dams 24 and 25, which are currently dormant. • Calcine Slimes Dams 26 and 27 have been reclaimed. • No 30, 30A, 31, 32, 33A, 34A, and 34B Slimes Dams are currently dormant.
Domestic and industrial waste	Standard operating procedures have been developed for waste management at the Central Operations. • Domestic waste generated at the Central Operations is taken off-site to a registered landfill site. • Industrial waste is handled at Central Plant and processing areas in designated waste areas. Scrap metal, wood and plastic are recycled through the Salvage Yard. • Hazardous waste is handled by the appointed contractor, currently Micro Trading, and is transported off-site to a registered hazardous waste facility.
Sewage	Sewage from the Central Operations is directed to the municipal sewage treatment plant.
Support infrastructure	
General infrastructure	The support infrastructure associated with the Central Operations includes: • Administration offices • Change houses • Engineering workshops • Salvage yard.

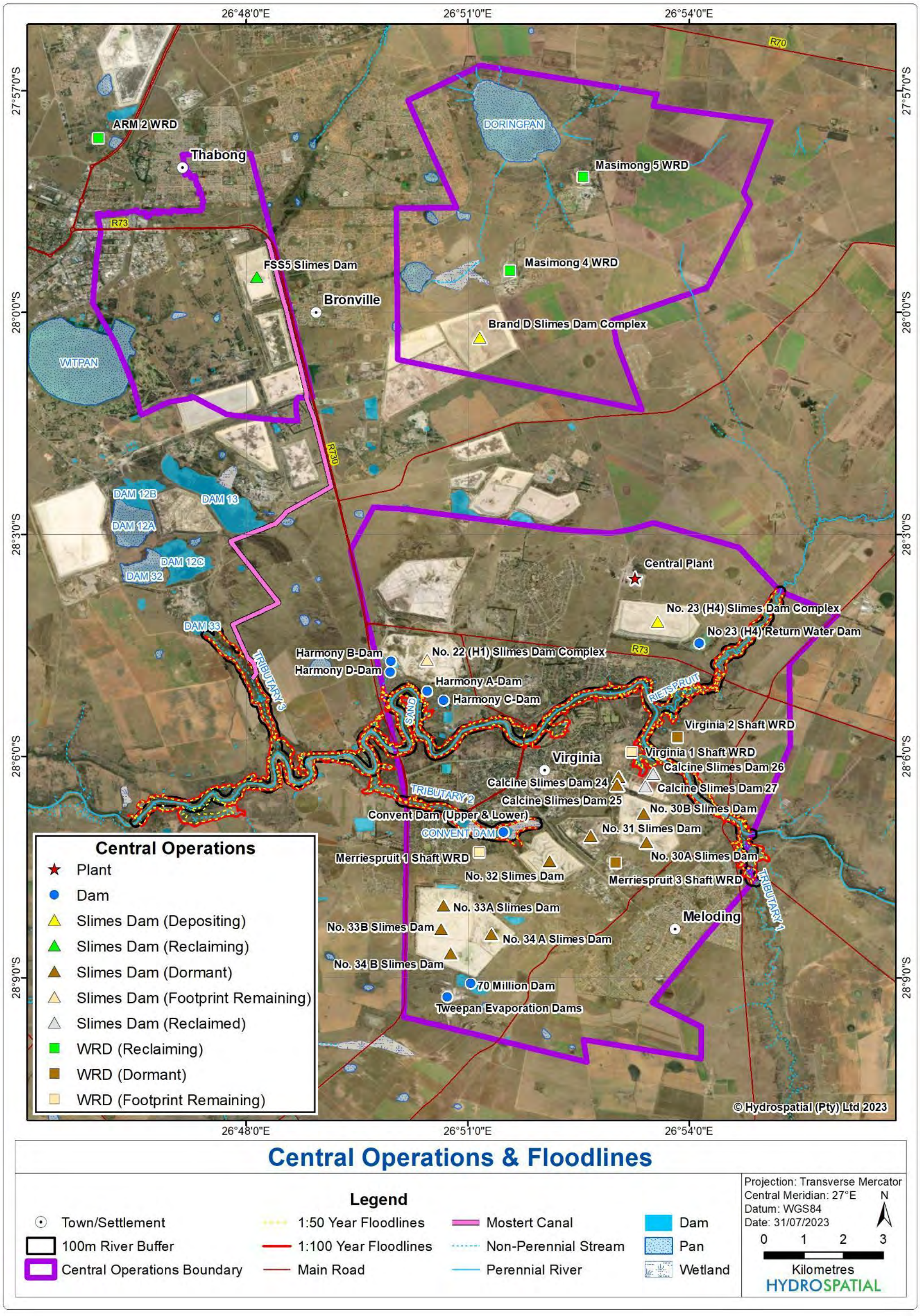


Figure 8-1: Central Operations and floodlines

8.2 Floodlines

The Sand River flows in a westerly direction through the Central Operations. The Rietspruit as well as an unnamed non-perennial tributary (referred to as Tributary 1), flow into the Sand River to the north-east and south-east of Virginia, respectively. Tributary 2 drains the south-western area of Virginia into the Convent Dams and then into the Sand River. The floodlines and 100 m buffers have been determined for these rivers. A summary of the estimated peak flows that were used to determine the floodlines is provided in Table 8-2, whilst the floodlines and 100 m river buffers are shown on Figure 8-1.

Table 8-2: Peak flows used to determine the floodlines for the Central Operations

River	Catchment Area (km^2)	Method	1:50 Year Peak Flow (m^3/s)	1:100 Year Peak Flow (m^3/s)
Sand River	6 472.81	Rational	1 634	2 194
		SCS	1 756	2 068
		Midgley & Pitman	1 684	2 127
		Average	**1 691**	**2 130**
Rietspruit	632.91	Rational	319	428
		SCS	334	414
		Midgley & Pitman	395	500
		Average	**349**	**447**
Tributary 1 of Sand River	53.06	Rational	71	94
		SCS	89	110
		Midgley & Pitman	87	110
		Average	**82**	**105**
Tributary 2 of Sand River	49.18	Rational	98	124
		SCS	104	129
		Midgley & Pitman	100	126
		Average	**101**	**126**

- The Convent Upper and Lower Dams are located within Tributary 2. No other mine infrastructure is located within the floodlines or within 100 m of a river.

8.3 GN R704 Audit

Figure 8-2 and Figure 8-3 indicate the locations of the non-compliances with GN R704, whilst Table 8-3 provides a summary of the non-compliances and recommendations for improvement at the Central Operations.

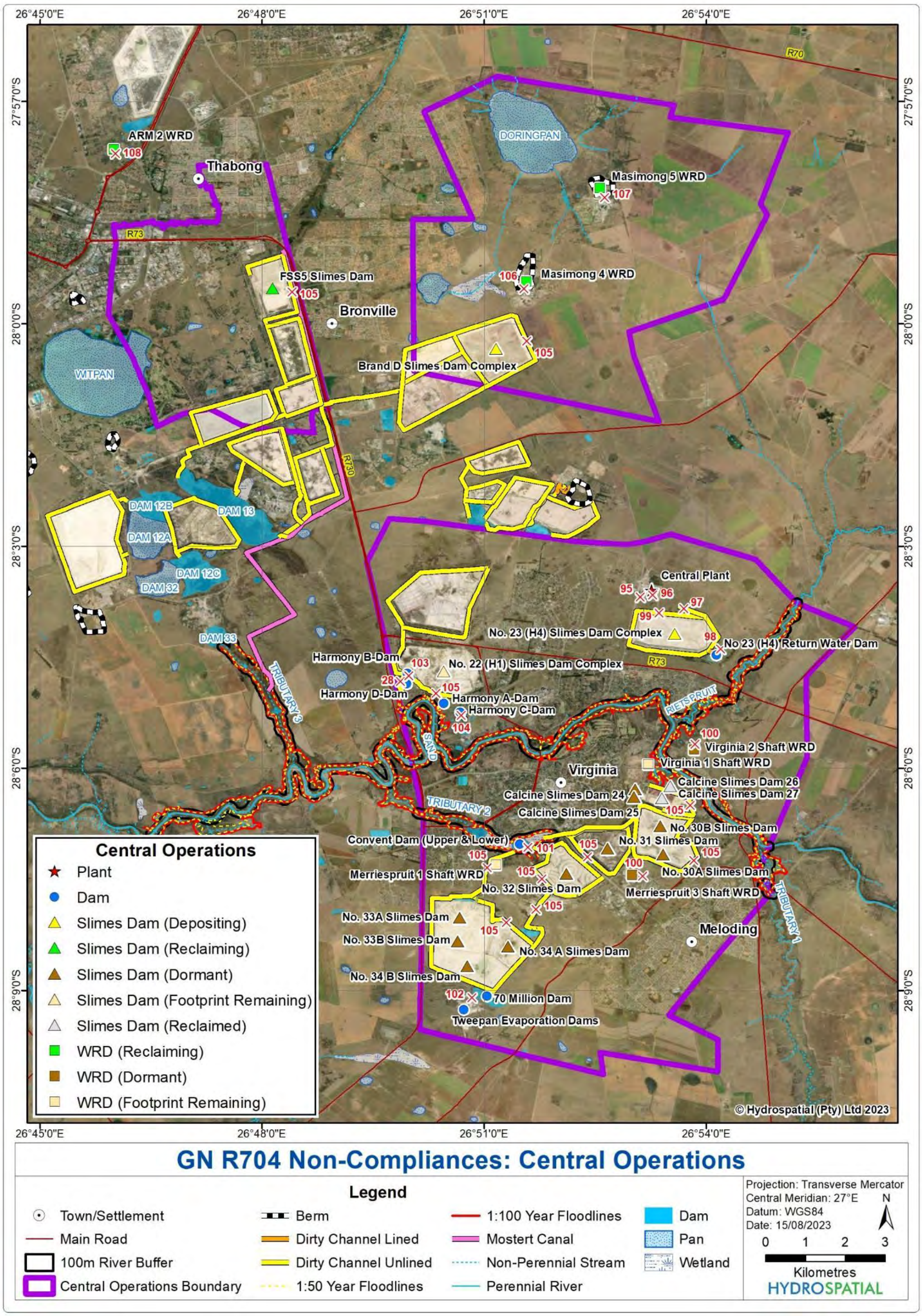


Figure 8-2: Location of the GN R704 non-compliances at the Central Operations



Figure 8-3: Location of the GN R704 non-compliances at the Central Operations Plant

Table 8-3: Central Operations GN R704 non-compliances and recommendations

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
Central – Plant	95	Regulation 6(d) & 7(a) – The pipeline outside of the Central Plant was leaking leading to ponding of water. 	The pipeline should be regularly monitored for leaks and repaired immediately.
Central – No. 23 (H4) Slimes Dam Complex	96 & 97	Regulation 6(d) & 7(a) – The No. 23 Slimes Dam Complex solution trench is unlined. The channel DC 14 that conveys dirty water from the plant to the No. 23 RWD is also unlined. 	The Slimes Dam is visible on aerial imagery that pre-dates June 1999 when GN R704 was enacted. Exemption should be applied for.
Central – No. 23 (H4) RWD	98	Regulation 7(a) – The No. 23 RWD unlined and is likely to seep dirty water. 	The RWD is visible on aerial imagery that pre-dates June 1999 when GN R704 was enacted. Exemption should be applied for.
Central – Plant	99	Regulation 6(d) – The channels at the Thickeners were very silted. 	According to Harmony, the channels at the Central Plant are only cleaned once they are silted. It is recommended that inspections of the channels and sumps are undertaken at least on a weekly basis, and that the removal of silt is undertaken more frequently.
Central – WRDs	100	Regulation 6(c), 6(d) & 7(a) – No measures to contain runoff and silt were noted at the following WRDs: • Virginia 2 Shaft WRD; • Merriespruit 3 Shaft WRD;	It is recommended that berms are constructed around the periphery of the WRDs.
Central – Convent Dam (Upper and Lower)	101	Regulation 4(a) – The Convent Upper and Lower Dams are located within a watercourse. Regulation 6(d) – The Convent Dams receive dirty water from the No. 30A, 30B, 31 & 32, 33A, 33B, 34A and 34B Slimes Dams. During the site visit, the Convent Dams were noted to be overflowing. Regulation 7(a) – The Convent Dams are unlined and likely to seep dirty water. Regulation 8(a) – The dams are not fenced-off to the public.	The water levels of all of the Harmony dams should be monitored. This can be done when water quality samples are taken from the dams. The dam levels should be recorded and reported on. The dams are visible on aerial imagery that pre-dates June 1999 when GN R704 was enacted. Exemption should be applied for.
Central – 70 Million Dam & Tweepan Evaporation Dams	102	Regulation 7(a) – These dams are unlined and likely to seep dirty water. Regulation 8(a) – The dams are not fenced-off to the public and no warning signs were noted.	The dams are visible on aerial imagery that pre-dates June 1999 when GN R704 was enacted. Exemption should be applied for. Warnings signs should be erected.

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
Central – No, 22 (H1) Slimes Dam Complex	28	Regulation 7(a) – The trenches that convey dirty water to the D-Dam are unlined. The D-Dam is also unlined. 	The No. 22 (H1) Slimes Dam is visible on aerial imagery that pre-dates GN R704, and it is therefore likely that the trenches and the D-Dam were in place. Exemption should be applied for.
Central – Harmony B-Dam	103	Regulation 6(c), 6(d) & 7(a) – The B-Dam was noted to be very silted and also appeared to be unlined. Regulation 8(a) – The dam is not fenced-off to the public. 	The B-Dam is visible on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Central – Harmony C-Dam	104	Regulation 6(c), 6(d) & 7(a) – The C-Dam was noted to be very full and overflowing. Furthermore, the dam is unlined. Regulation 8(a) – The dam is not fenced-off to the public and no warning signs were noted. 	The water levels of all of the Harmony dams should be monitored. This can be done when water quality samples are taken from the dams. The dam levels should be recorded and reported on. Warnings signs should be erected. The C-Dam is visible on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Central – Dormant Slimes Dams	105	Regulation 6(d) & 7(a) – The dirty channels surrounding the slimes dams are unlined. Furthermore, many of the channels were noted to be silted.	It is recommended that the channels surrounding the slimes dams as well as those leading to the Convent Dams are inspected and desilted. All slimes dams are visible on aerial imagery that pre-dates June 1999 when GN R704 was enacted. Exemption should be applied for.
Central – Masimong 4 & 5 WRDs	106 & 107	Regulation 6(c) & 6(d) – Berms have been constructed around the Masimong 4 & 5 WRDs, however, the berms do not fully surround the WRDs. Regulation 5 – Waste rock that may potentially be hazardous, has been used in the construction of the berms.	The berms should fully surround the WRDs. A geochemical assessment should be undertaken on the waste rock to determine whether it is hazardous. The WRDs are visible on aerial imagery that pre-dates June 1999 when GN R704 was enacted.
Central – ARM 2 WRD	108	Regulation 6(c) & 6(d) – Runoff and silt from the ARM 2 WRD is uncontained.	A berm should be constructed around the WRD.

8.4 Conceptual Stormwater Management Plan

The existing and proposed stormwater measures at the Central Operations are shown on Figure 8-4 and Figure 8-5 and are described below.

8.4.1 Existing Stormwater Measures

The following are existing stormwater measures at the Target Operations.

8.4.1.1 Central Plant

- The Central Plant is slightly raised and surrounded by a concrete wall, and therefore it is unlikely that clean runoff will flow into the plant;
- Dirty areas at the plant are concrete lined and bunded and report to sumps that either pump back into the process, or report to channel DC14 that conveys dirty water to the No. 23 RWD;
- Channel DC15 captures spills from the thickeners and reports to Sump S36 that pumps dirty water back into the process. Spills from the thickeners are also captured in Sump S35; and
- Stormwater inlets are located along the sides of the roads and convey runoff to channel DC14 that flows to the No. 23 RWD.

8.4.1.2 Waste Rock Dumps

The existing stormwater measures at the WRDs include berms around the Masimong 4 and 5 WRDs, however, there are sections where the berms are disconnected. The ARM 2 WRD, Virginia 2 Shaft WRD and Merriespruit 3 Shaft WRD do not contain berms.

8.4.1.3 Slimes Dams

Unlined trenches have been constructed around the slimes dams which convey seepage and runoff to dirty water dams.

8.4.2 Clean and Dirty Areas

The dirty areas at the Central Operations include the TSFs / Slimes Dams, WRDs, RWDs, evaporation dams and plant. Dirty areas should be contained to ensure that they do not flow or seep into clean areas. The remaining areas should be managed as clean areas, which should not be contaminated by dirty areas, or flow into dirty areas. Figure 8-4 and Figure 8-5 show the clean and dirty areas at the Central Operations.

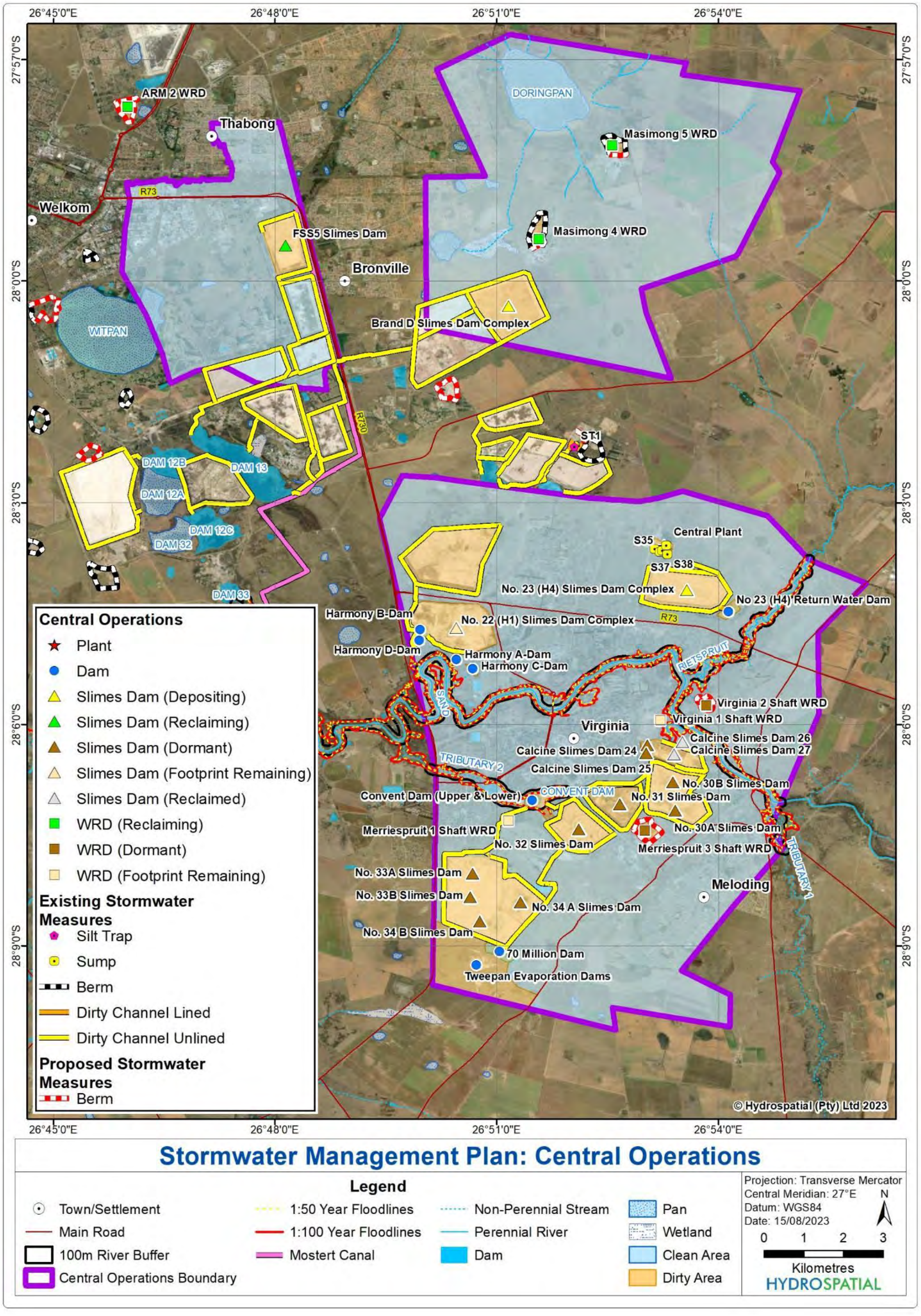


Figure 8-4: Conceptual stormwater management plan for the Central Operations



Figure 8-5: Conceptual stormwater management plan for the Central Operations Plant

8.4.3 Proposed Stormwater Measures and Recommendations

The following are proposed stormwater measures and recommendations for the Target Operations:

8.4.3.1 Central Plant

The channels and sumps at the Central Plant should be inspected and desilted on a more frequent basis than currently.

8.4.3.2 Waste Rock Dumps

Berms that fully surround the Masimong 4 and 5 WRDs should be constructed. Berms should also be constructed around the ARM 2 WRD, Virginia 2 Shaft WRD and Merriespruit 3 Shaft WRD.

8.4.3.3 Slimes Dams

The slimes dam channels were noted to be silted and disconnected in certain areas. It is recommended that the channels are inspected and that they are desilted and repaired where necessary.

In addition to the above, the recommendations provided in Table 8-3 should be implemented.

9 HARMONY 1 OPERATIONS

9.1 Description of Operations

The infrastructure that forms part of the Harmony 1 Operations is shown on Figure 9-1. It should be noted that the boundary of the Harmony 1 Operations overlaps with the Central and Saaiplaas Operations. According to SRK (2020b), the Harmony 1 Plant receives ore from Phakisa, Tshepong, Joel and Masimong Shafts, as well as from the Freddie's 9 and Nyala WRDs. The Bambanani and Unisel Shafts that previously supplied the plant have been closed.

The Tshepong Shaft initiated its productions in 1986 and is Harmony's largest operation in the Free State, which comprisesof a single vertical shaft that extends to a depth of 2 154 m below surface.

The Phakisa Shaft uses conventional scattered stoping methods to mine the basal reef at depths of up to 2 400 m. Nyala Shaft is situated approximately 4 km west of Phakisa Shaft and is a services shaft to the Phakisa Shaft, used for the hoisting of all ore and waste from the Phakisa workings. The ore is hoisted halfway up Phakisa Shaft via an underground winder and is transported underground to the loading and hoisting facilities at Nyala Shaft. Nyala Shaft is also used to dewater the Phakisa Shaft workings, as an exhaust ventilation airway and used as an escape way from the Phakisa Shaft.

Masimong 4 Shaft is used for pumping, ventilation and as an emergency outlet. Ore production at this shaft ceased in April 2005 and has been placed under care and maintenance. Masimong 5 Shaft is a production shaft, where all ore and waste rock are hoisted to the surface. The depth of mining at this shaft extends to 2 150 m below surface and the main reef mined is the Wits Reef. Mining is undertakenusing traditional drill, blast and scrape methods for the extraction of the narrow and wide reef.

A summary of the activities undertaken at the Harmony 1 Operations is provided in Table 9-1 and was adapted from SRK (2020b).

Table 9-1: Summary of activities undertaken at the Harmony 1 Operations

Aspect	Method/System
Mining	
Underground mining	• There are nine shafts at Harmony 1 Operations. Mining is currently undertaken at Phakisa, Masimong 5, Nyala and Tshepong Shafts. Bambanani and Masimong 4 shafts are currently under care and maintenance. Eland Shaft is used as a pumping shaft, whilst Unisel was being demolished at the time of the site visit. • The Basal, Leader and Middle reefs are mined. • Mining depths are currently approximately between 2 150 m and 2 400 m.
Beneficiation	
Metallurgy plants	• Mined ore is processed at the Harmony 1 Plant. • Gold is smelted at the Harmony 1 Plant. • Mineral waste products from the plant are currently deposited at the FSS 2 and St Helena 1,2,3 Slimes Dams.
Water and Waste Management Systems	
Water supply	• The Harmony 1 Operations receive water supply from Sedibeng Water, which is usedfor domestic purposes, and supplement for mining and metallurgical purposes. • The Nyala water treatment plant treats underground water, which is then supplied tothe Tshepong/Nyala Hostel and Nyala Shaft as potable water.
Dirty (waste) water containment and release	• Dirty water (process water) is contained in process water dams and stormwater dams. • Dirty water runoff from the shafts and processing areas is contained in the dirty watercontainment facilities, including the return water dams. • Water from the dirty water containment facilities including the RWDs is reused in the mining process.
Clean water diversions	Clean water diversions are in place at the shafts and processing plant areas to direct runoff from the surrounding catchment, away from the dirty areas.
Waste rock	The shaft waste rock dumps and final destination of the waste rock are as follows: • Waste rock from the Nyala Shaft and Tshepong Shaft is sent to the respective shafts' waste rock dump. The waste rock from the Nyala Shaft Waste Rock Dump is sent to the Harmony 1 Plant to be processed. • Waste rock from the Masimong 4 Shaft and Masimong 5 Shaft is sent to the shafts' waste rock dumps. The waste rock from these waste rock dumps is sent to the Harmony 1 Plant to be processed. • No waste rock is generated from the Bambanani West Shaft, Bambanani East Shaft, Eland Shaft and Unisel Shaft. • The ARM waste rock dumps are dormant and waste rock is reclaimed for aggregate production.
Tailings	• Tailings are transported via pipeline to the FSS 2 and St Helena 1,2,3 Slimes Dams. • These slimes dams will continue to receive tailings until the life of mine. • Tailings from Harmony 1 Plant is also transported to the Bambanani West Backfill Plant to be used as backfill for the shaft. • FSS1, FSS3, FSS4, FSS6, FSS7, FSS8, FSN1, FSN 2, FSN 3A, FSN 5, FSN 6 and ARM Slimes Dams are currently dormant.

Aspect	Method/System
Domestic and industrial waste	Standard operating procedures have been developed for waste management at the Harmony 1 Operations. • Domestic waste generated at the Harmony 1 Operations is taken off-site to a registered landfill site. • Industrial waste is handled at the shaft and processing areas in designated waste areas. Scrap metal, wood and plastic are recycled through the Salvage Yard. • Hazardous waste is handled by the appointed contractor, currently Micro Trading, and is transported off-site to a registered hazardous waste facility.
Sewage	• Sewage effluent from and Nyala Shaft is handled at the FSG2 STP and is recycled in the process. • Sewage from the Tshepong and Phakisa shafts is directed to the Matjhabeng Municipal Sewage Treatment Facility. • Sewage from the Harmony 1 Plant Masimong 4 and 5, Bambanani East and West Shafts is directed to the Witpan Municipal Wastewater Treatment Plant.
Support infrastructure	
General infrastructure	The support infrastructure associated with the Harmony 1 Operations includes: • Administration offices • Change houses • Engineering workshops • Salvage yard.

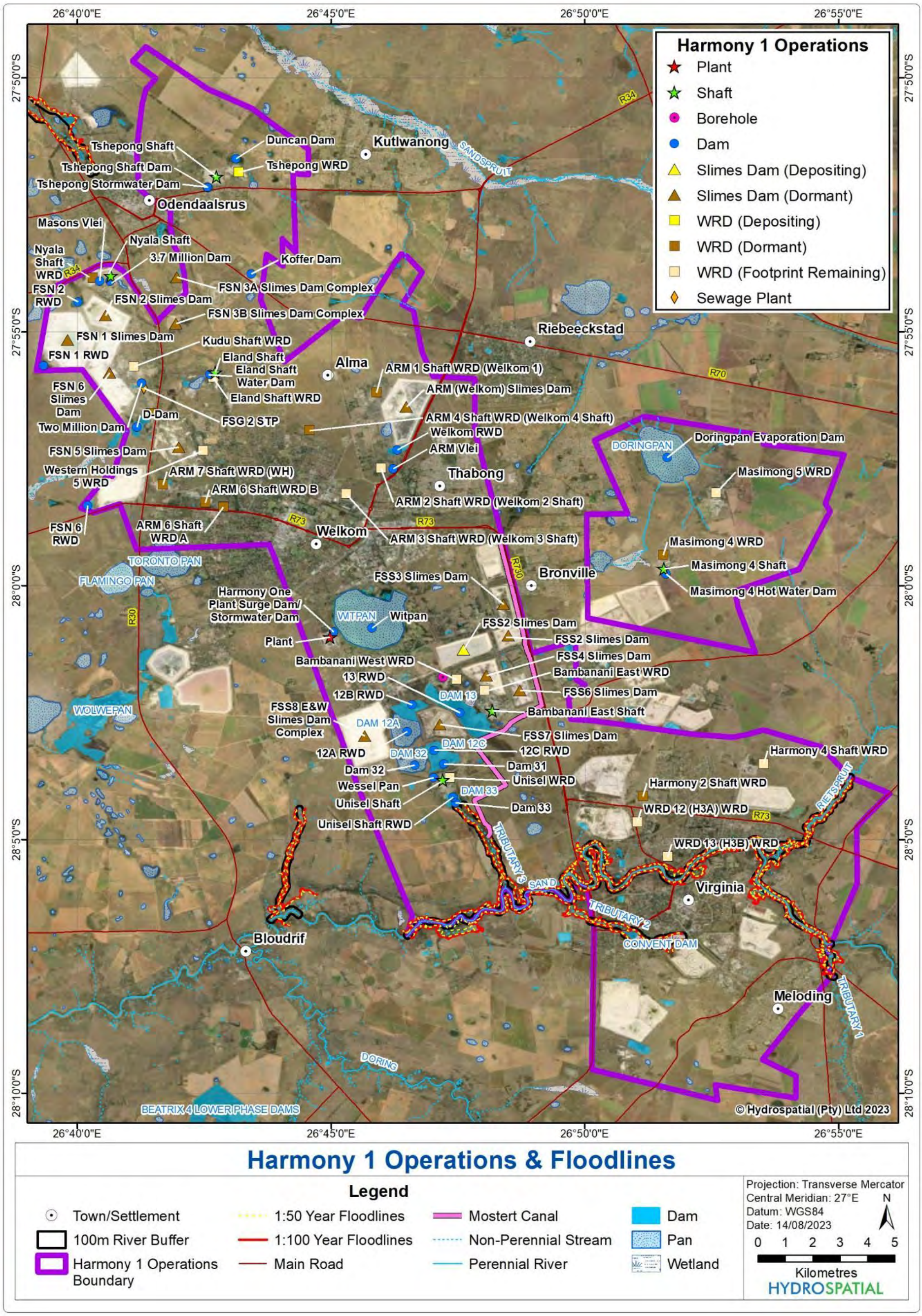


Figure 9-1: Harmony 1 Operations and floodlines

9.2 Floodlines

The Sand River flows in a westerly direction through the Harmony 1 Operations. The Rietspruit as well as an unnamed non-perennial tributary (referred to as Tributary 1), flow into the Sand River to the north-east and south-east of Virginia, respectively. Tributary 2 drains the south-western area of Virginia into the Convent Dams and then into the Sand River. Tributary 3 flows in a south-easterly direction from Dam 33 near the old Unisel Shaft into the Sand River. This tributary receives runoff from the Mostert Canal, which is a stormwater canal, as well as from overflows from the dams to the north. The floodlines and 100 m buffers have been determined for these rivers. A summary of the estimated peak flows that were used to determine the floodlines is provided in Table 9-2, whilst the floodlines and 100 m river buffers are shown on Figure 9-1.

Table 9-2: Peak flows used to determine the floodlines for the Harmony 1 Operations

River	Catchment Area (km^2)	Method	1:50 Year Peak Flow (m^3/s)	1:100 Year Peak Flow (m^3/s)
Sand River	6 472.81	Rational	1 634	2 194
		SCS	1 756	2 068
		Midgley & Pitman	1 684	2 127
		Average	**1 691**	**2 130**
Rietspruit	632.91	Rational	319	428
		SCS	334	414
		Midgley & Pitman	395	500
		Average	**349**	**447**
Tributary 1 of Sand River	53.06	Rational	71	94
		SCS	89	110
		Midgley & Pitman	87	110
		Average	**82**	**105**
Tributary 2 of Sand River	49.18	Rational	98	124
		SCS	104	129
		Midgley & Pitman	100	126
		Average	**101**	**126**
Tributary 3 of Sand River	307.52	Rational	221	284
		SCS	251	309
		Midgley & Pitman	253	319
		Average	**242**	**304**

Dam 33 is located within 100 m of Tributary 3. No other mine infrastructure associated with the Harmony 1 Operations is located within the floodlines or within 100 m of a river.

9.3 GN R704 Audit

Figure 9-2 to Figure 9-10 indicate the locations of the non-compliances with GN R704, whilst Table 9-3 provides a summary of the non-compliances and recommendations for improvement at the Harmony 1 Operations.

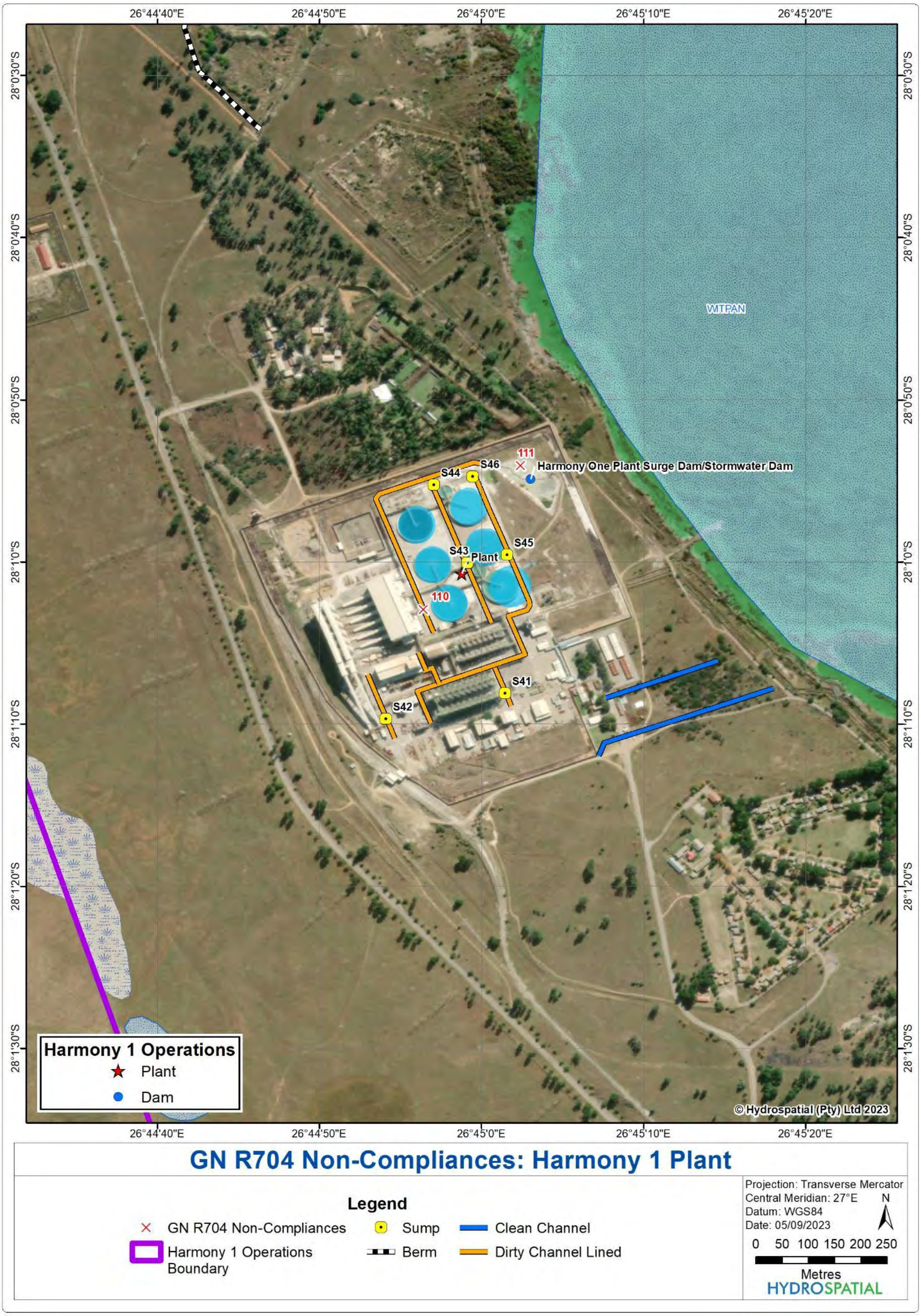


Figure 9-2: Location of the GN R704 non-compliances at the Harmony 1 Plant

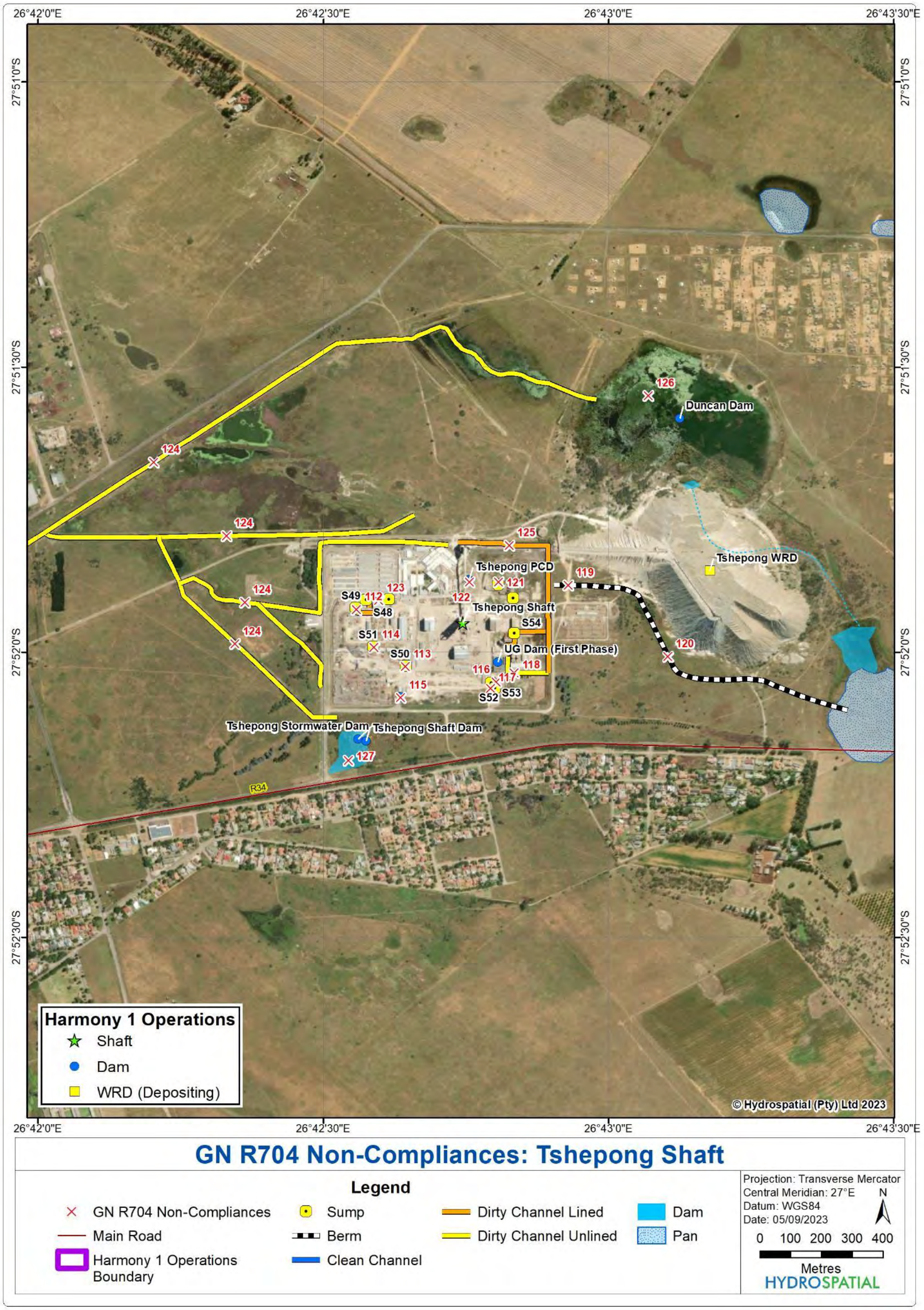


Figure 9-3: Location of the GN R704 non-compliances at the Tshepong Shaft

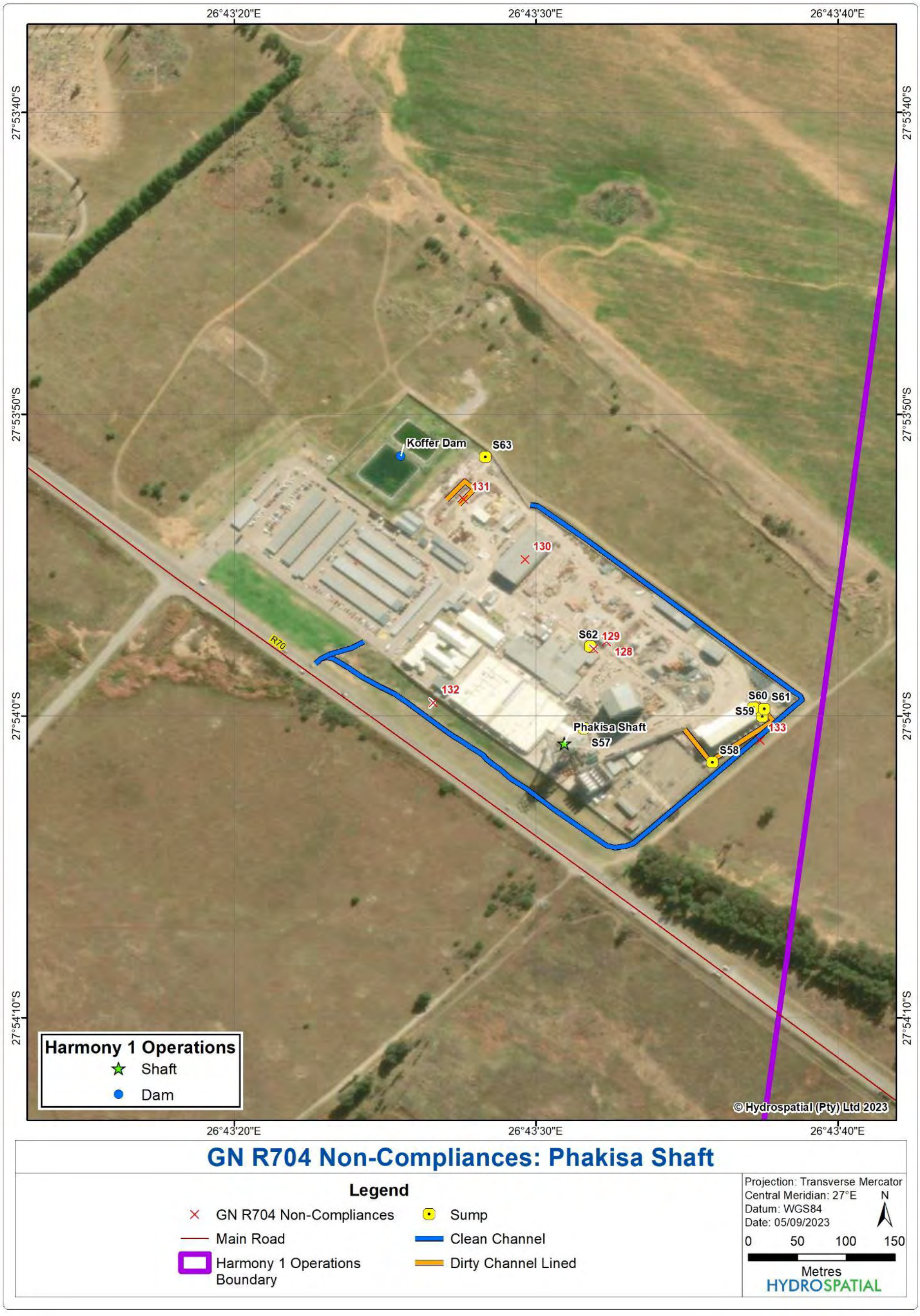


Figure 9-4: Location of the GN R704 non-compliances at the Phakisa Shaft

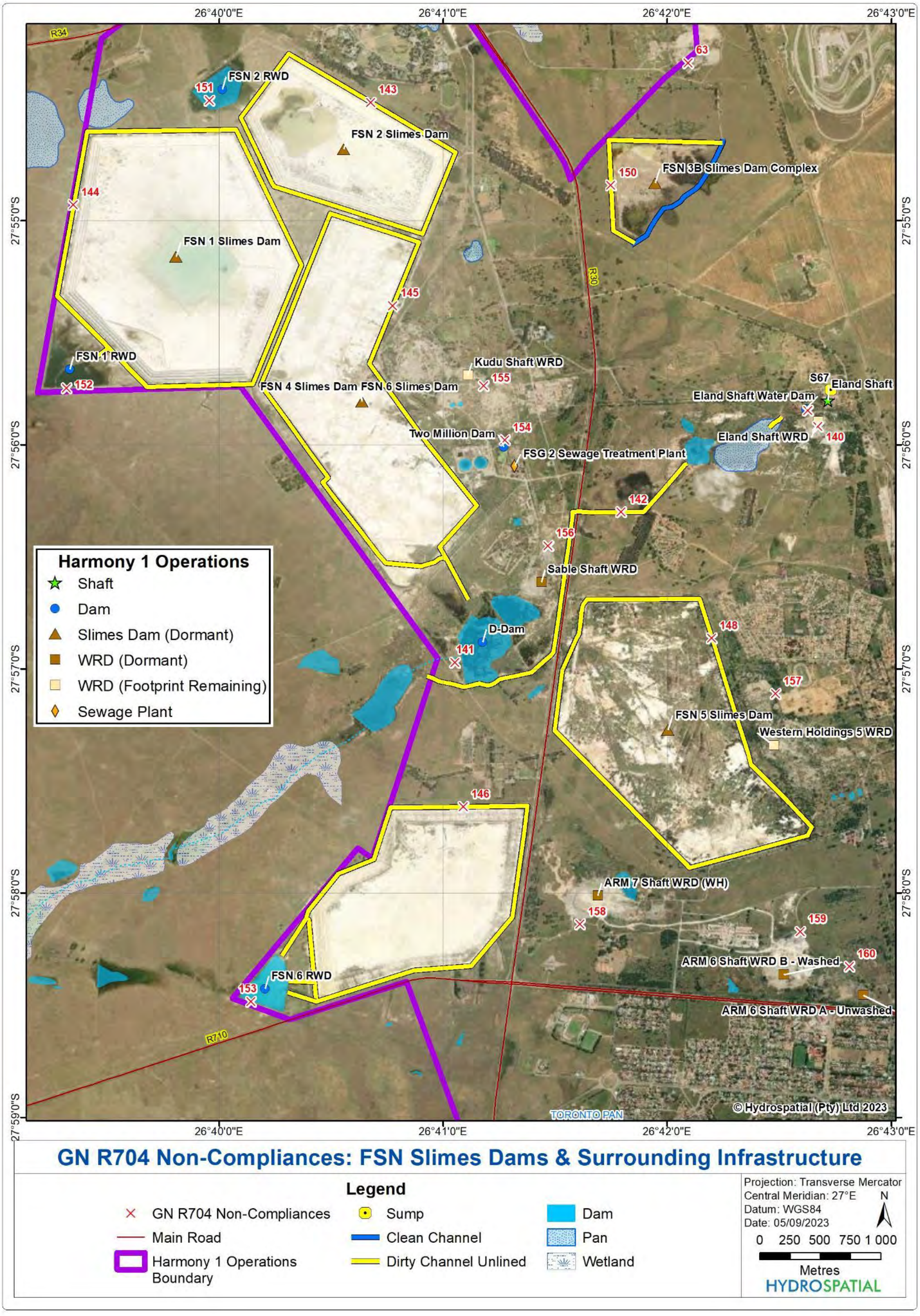


Figure 9-5: Location of the GN R704 non-compliances at the FSN Slimes Dams and surrounding infrastructure

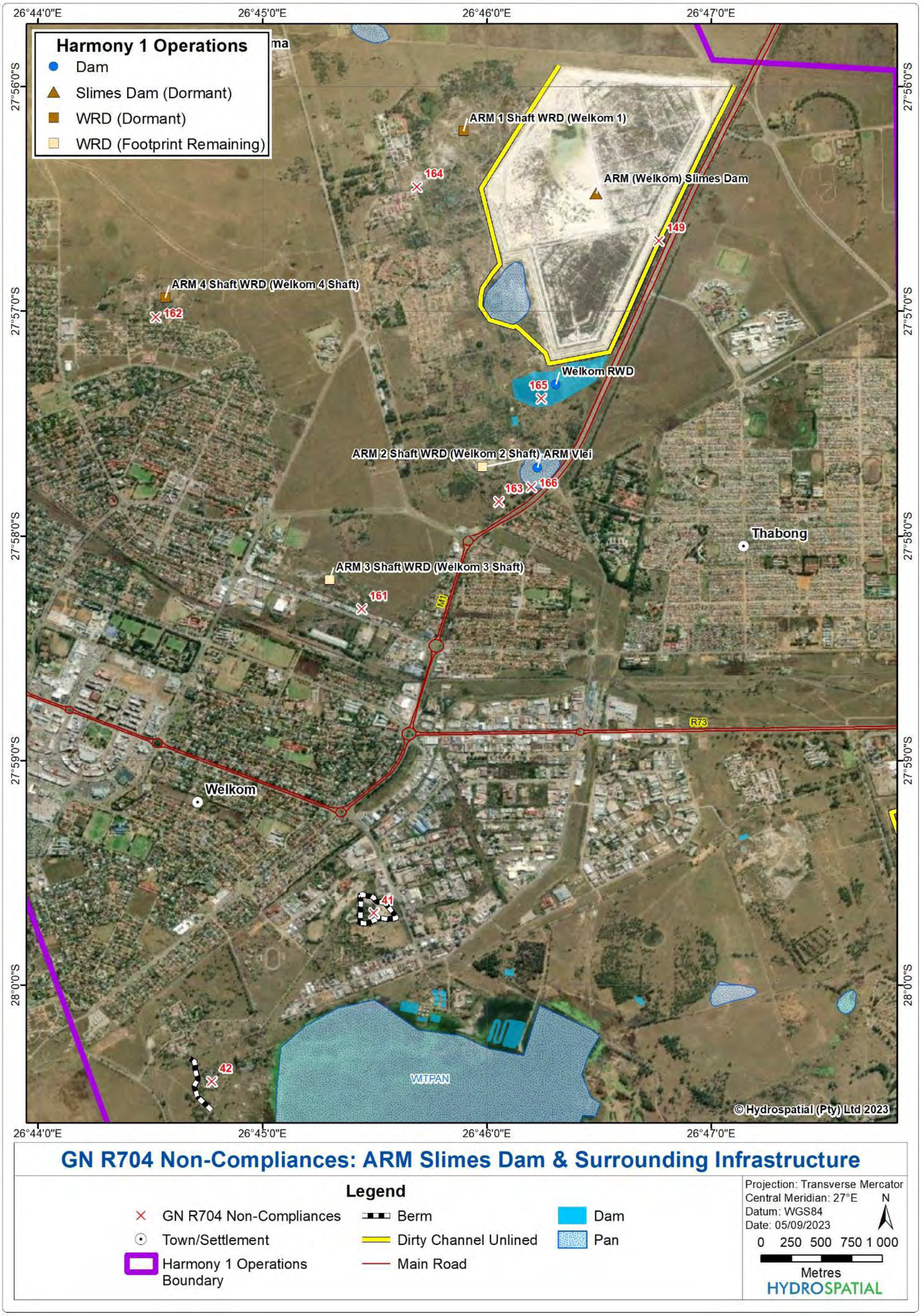


Figure 9-6: Location of the GN R704 non-compliances at the ARM Slimes Dam and surrounding infrastructure

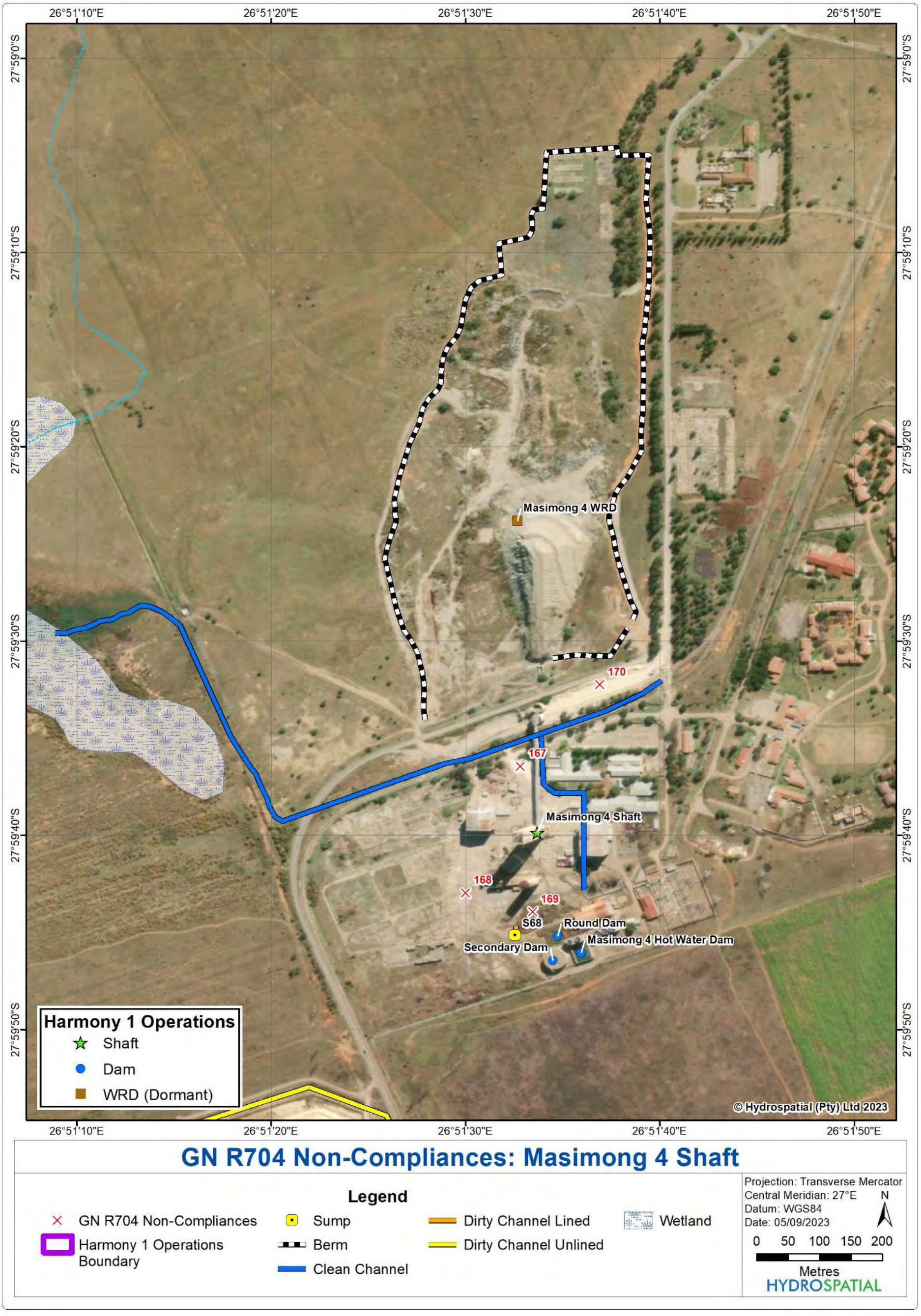


Figure 9-7: Location of the GN R704 non-compliances at the Masimong 4 Shaft



Figure 9-8: Location of the GN R704 non-compliances at the Masimong 5 Shaft

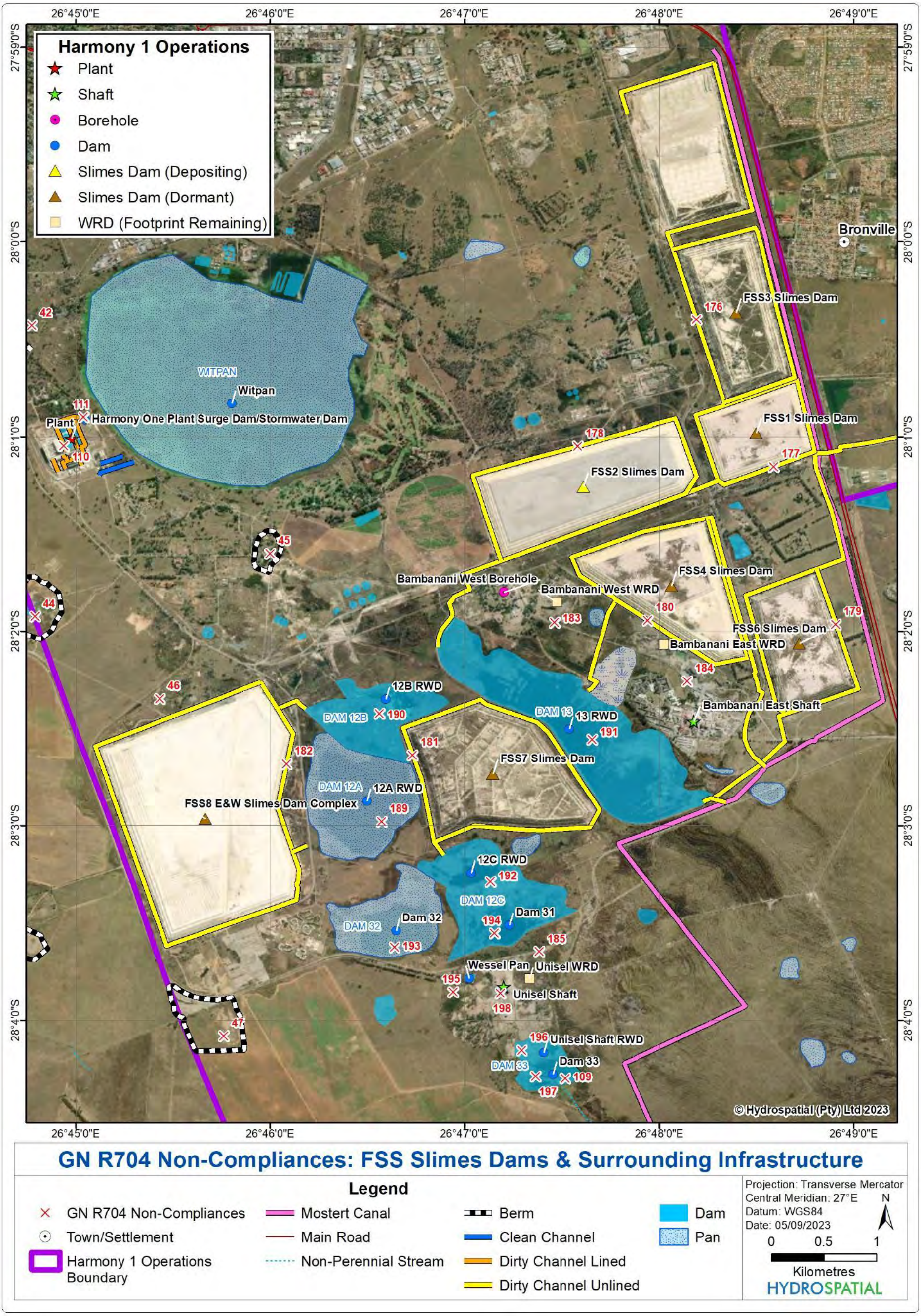


Figure 9-9: Location of the GN R704 non-compliances at the FSS Slimes Dams and surrounding infrastructure

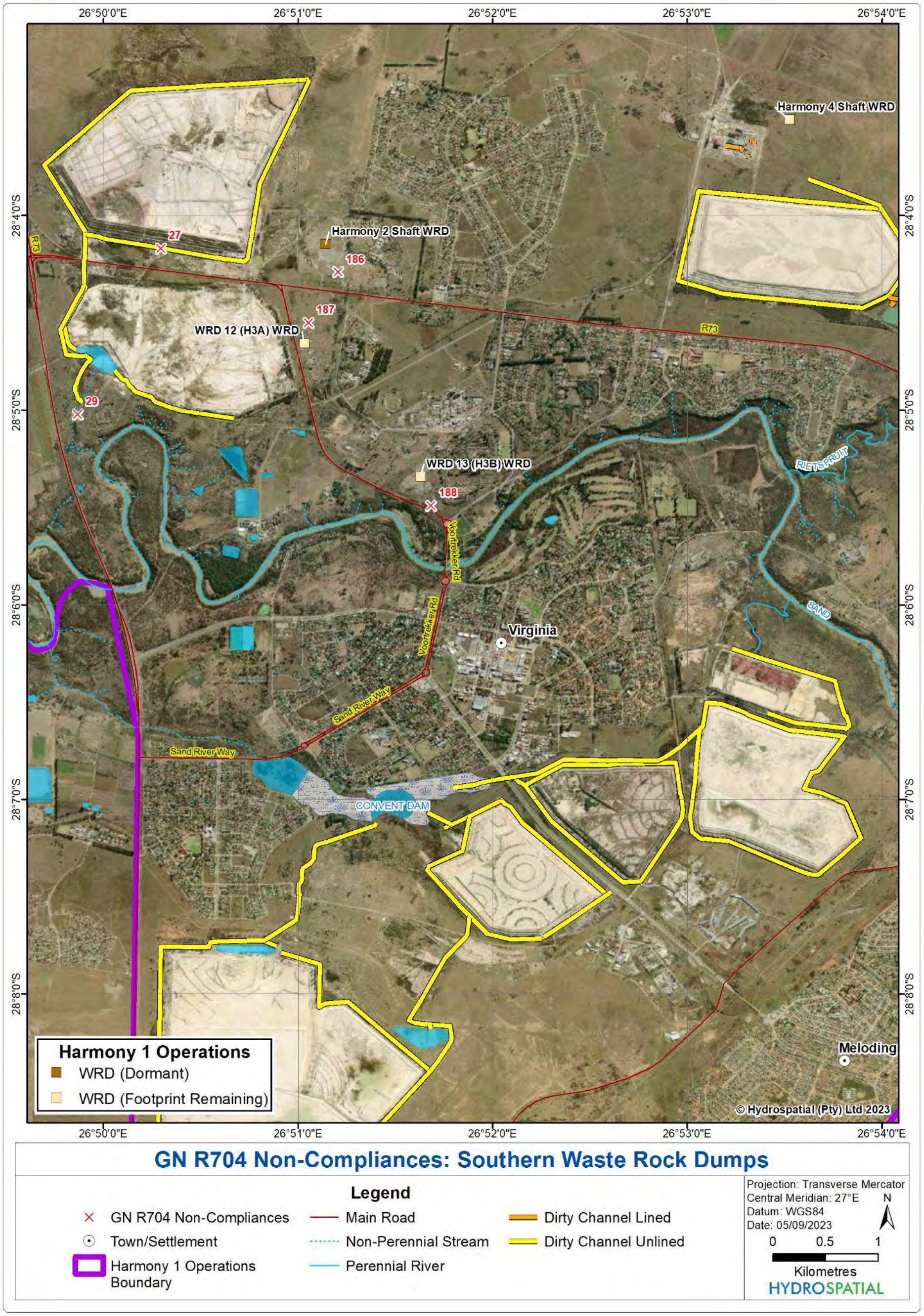
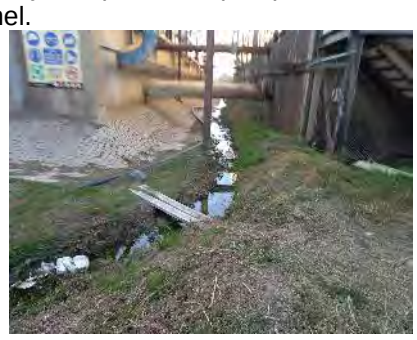


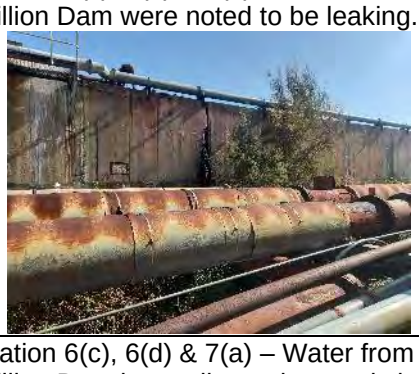
Figure 9-10: Location of the GN R704 non-compliances at the southern waste rock dumps

Table 9-3: Harmony 1 Operations GN R704 non-compliances and recommendations

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
Harmony 1 – Dam 33	109	Regulation 4(a) – Dam 33 is located within 100 m of a watercourse.	The dams are visible on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Harmony 1 – Plant	110	Regulation 6(d) – The channel at the milling area was noted to contain vegetation and was silted. 	Remove vegetation and desilt channel.
Harmony 1 – Plant	111	Regulation 6(d) – The Surge Dam was noted to be heavily silted at the time of the site visit. 	The Surge Dam should not be allowed to become so heavily silted as this may lead to overflows. Cleaning of the Surge Dam should happen on a more frequent basis.
Harmony 1 – Tshepong Shaft	112	Regulation 6(d) – Silted channel leading to Sump S49. 	The channels and sumps are inspected on an ad hoc basis. It is recommended that they are routinely inspected at least once per a week, as well as after storm events.
Harmony 1 – Tshepong Shaft	113	Regulation 6 (c) & (d) – Informal Sump S50. The sump collects dirty water from the IMS area and is fitted with a pump in the rainy season. The sump was noted to contain plastic and debris. The destination to where water is pumped to from this sump is unknown, and is thought to be pumped to the nearby street. 	The sump should be fitted with a formal grid to prevent debris and material from flowing into it. Furthermore, it should be ensured that the sump pumps to a dirty water facility.
Harmony 1 – Tshepong Shaft	114	Regulation 6 (c) & (d) – Sump S51 is connected to an oil water separator and was noted to be relatively full. The oil water separator was not working at the time of the site visit. 	The oil water separator should be repaired and the sump should be operated at a much lower level (preferably dry). Water from the oil water separator should be pumped to a dirty water facility.
Harmony 1 – Tshepong Shaft	115	Regulation 6(b) – According to Harmony, only clean water drains from the HPE Workshop via a concrete channel towards a grassed area above the Tshepong Stormwater Dam. This system appeared to be informal.	Formalise the drainage system from the HPE Workshop. It should be ensured that only clean water drains from the HPE Workshop to the Tshepong Stormwater Dam.

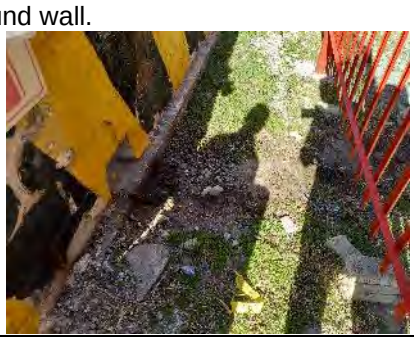
Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
			
Harmony 1 – Tshepong Shaft	116	Regulation 6(d) – The wash bays were noted to be silted. This appears to be affecting the pumps at Sumps S52 and S53 leading to flooding and spills at the wash bays. 	It is recommended that the wash bays are inspected and desilted more frequently than currently. This will prevent silt from affecting the pumps.
Harmony 1 – Tshepong Shaft	117	Regulation 6(c) & (d) – Gap in the bund wall which could lead to rainwater entering or possibly spills. 	The gap in the wall should be sealed.
Harmony 1 – Tshepong Shaft	118	Regulation 6(c), 6(d) & 7(a)– Spills from the UG Dam and Fridge Plant report to an informal unlined channel (DC17) that conveys dirty water to Freddie's RWD. Dirty water from the wash bay sumps is also pumped into this channel. 	Dirty channel DC17 should be formalised and lined.
Harmony 1 – Tshepong Shaft	119 & 120	Regulation 6(c), 6(d) and 7(a) – The berm around the Tshepong WRD has gaps in it where the roads cross the berm. Furthermore, the berm does not fully surround the WRD.	Ramps should be constructed where roads cross the berm. The berm should as far as possible surround the WRD.
Harmony 1 – Tshepong Shaft	121	Regulation 6(d) – Sump S56 is not fitted with a pump and therefore the area at the extraction fans was flooded at the time of the site visit. 	A pump should be fitted to Sump S56.
Harmony 1 – Tshepong Shaft	122	Regulation 8(a) – No warning signs were noted at the Tshepong PCD.	Warning signs should be erected.

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
			
Harmony 1 – Tshepong Shaft	123	Regulation 6(c) – The Workshop basin that is used for hand washing drains to the parking area and is not captured in a formal system.	It is recommended that the basin drains to a dirty water facility such as Sumps S47 or S48.
Harmony 1 – Tshepong Shaft	124	Regulation 7(a) – The channels conveying dirty water from the Tshepong Shaft to Freddie's RWD are unlined. 	It is unclear from historical imagery whether these channels were constructed prior to June 1999 when GN R704 was enacted. However, the channels convey water to Freddie's RWD which is an unlined facility that was constructed prior to GN R704.
Harmony 1 – Tshepong Shaft	125	Regulation 6(d) & 7(a) – The concrete dirty channel DC20 was noted to be damaged. 	The channel should be repaired to prevent seepage and overflows of dirty water.
Harmony 1 – Tshepong Shaft	126	Regulation 7(a) – The Duncan Dam is an unlined facility. Regulation 8(a) – The Duncan Dam was not noted to be fenced-off to the public or to have warning signs erected in prominent locations.	It is unclear from historical imagery whether this dam was constructed prior to June 1999 when GN R704 was enacted.
Harmony 1 – Tshepong Shaft	127	Regulation 7(a) – The Tshepong Stormwater Dam is an unlined facility. Regulation 8(a) – The Tshepong Stormwater Dam was not noted to be fenced-off to the public or to have warning signs erected in prominent locations.	The dam is visible on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Harmony 1 – Phakisa Shaft	128	Regulation 6(d) & 7(a) – Seepage from the bund wall of the Diesel Bay. 	The Diesel Bay bund wall should be sealed/repaired to prevent further seepage of hydrocarbons.
Harmony 1 – Phakisa Shaft	129	Regulation 6(c), 6(d) & 7(a) – Water captured in Sump S62 at the Mine Store is apparently pumped out onto the nearby road.	It is recommended that the water from Sump S62 reports to a dirty water facility such as the Koffer Dam.
Harmony 1 – Phakisa Shaft	130	Regulation 6(c), 6(d) & 7(a) – Dirty water was noted to be emanating from the Jig Workshop. 	Equipment and materials from which hydrocarbons may leak or spill were noted at the Jig Workshop. Although mostly stored in bunded areas, hydrocarbon spills were noted on the floor of the workshop. It is recommended that the workshop area reports to a sump which can pump to the Koffer Dam.

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
			
Harmony 1 – Phakisa Shaft	131	Regulation 6(c), 6(d) & 7(a) – Informal channel on the southern side of the Wash Bay. 	The channel should be formalised and concrete lined.
Harmony 1 – Phakisa Shaft	132	Regulation 6(c), 6(d) & 7(a) – Seepage into clean channel CC10, possibly from the Change Houses. The Change House water should be treated as dirty water. 	It is recommended that the source of the seepage is investigated, to determine whether it is clean or dirty water. If dirty water, then it should report to a dirty water facility.
Harmony 1 – Phakisa Shaft	133	Regulation 6(c), 6(d) & 7(a) – Seepage into clean channel CC10 most likely coming from the Ice Plant. The Ice Plant receives water from the Koffer Dam from time to time, and is therefore potentially dirty water. 	The seepage should be investigated and should be stopped if it is found to be dirty water.
Harmony 1 – Nyala Shaft	134	Regulation 6(c), 6(d) & 7(a) – Ponding of water most likely emanating from the Compressor House, which may potentially contain hydrocarbons. 	Leaking pipes at the Compressor House must be maintained and repaired. Daily inspections should be undertaken to ensure that leaks are identified and repaired immediately.
Harmony 1 – Nyala Shaft	135	Regulation 6(c), 6(d) & 7(a) – The walls of the 3.7 Million Dam were noted to be leaking. 	The leaks from the walls of the 3.7 Million Dam should be repaired.
Harmony 1 – Nyala Shaft	136	Regulation 6(c), 6(d) & 7(a) – Water from the 3.7 Million Dam is not directed properly into the surrounding channel resulting in spills to the environment.	

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
			
Harmony 1 – Nyala Shaft	137	Regulation 8(a) – Masons Vlei is not fenced-off to the public and warning signs in prominent locations were not noted. Regulation 7(a) – Masons Vlei is an unlined facility receiving process water from the 3.7 Million Dam.	It is unclear from historical imagery whether this facility was in place prior to June 1999 when GN R704 was enacted. This should be determined and if so then exemption should be applied for.
Harmony 1 – Nyala Shaft	138	Regulation 6(c), 6(d) and 7(a) – The berm around the Nyala WRD does not fully surround it.	The berm should as far as possible surround the WRD to contain silt and runoff.
Harmony 1 – Eland Shaft	139	Regulation 8(a) – The Eland Shaft Water Dam is not fenced-off to the public and warning signs in prominent locations were not noted. 	It is unclear from historical imagery whether this facility was in place prior to June 1999 when GN R704 was enacted, however, the shaft and surrounding infrastructure is visible and it is therefore likely that it was constructed prior to GN R704. This should be determined and if so then exemption should be applied for.
Harmony 1 – Eland Shaft	140	Regulation 6(c), 6(d) and 7(a) – The Eland WRD is not contained.	A berm should be constructed around the WRD to contain silt and runoff.
Harmony 1 – D-Dam	141	Regulation 6(c), 6(d) and 7(a) – The D-Dam is unlined and was noted to be seeping onto the road immediately to the west.  Regulation 8(a) – The D- Dam is not fenced-off to the public.	The dam is visible on aerial imagery that pre-dates GN R704. The seepage could potentially be captured in a paddock or trench constructed immediately downstream and pumped back into the dams.
Harmony 1 – D-Dam	142	Regulation 6(c), 6(d) and 7(a) – Unlined trench conveying dewatered groundwater from the Eland Shaft Water Dam to the D-Dam.	The Eland Shaft and D-Dam are visible on aerial imagery that pre-dates GN R704, and therefore, the trench was most likely constructed prior to GN R704.
Harmony 1 – FSN 1, FSN 2, FSN 3B, FSN 5, FSN 6 and ARM Slimes Dams.	143 – 150	Regulation 6(c), 6(d) and 7(a) – Unlined solution trenches surrounding the slimes dams.	The Slimes Dams are visible on aerial imagery that pre-dates GN R704. Exemption should be applied for.
Harmony 1 – FSN 1, FSN 2 and FSN 6 RWDs	151 – 153	Regulation 6(c), 6(d) and 7(a) – Unlined RWDs that were noted to be seeping water. Regulation 8(a) – The RWDs are not fenced-off to the public and the warning signs were noted to be old and worn and need to be replaced.	The RWDs are all visible on aerial imagery that pre-dates GN R704. The seepage could potentially be captured in a paddock or trench constructed immediately downstream and pumped back into the dams.
Harmony 1 – Two Million Dam	154	Regulation 8(a) – The dam is not fenced-off to the public.	It is unclear from historical imagery whether this facility was in place prior to June 1999 when GN R704 was enacted.
Harmony 1 – WRDs	155 – 164	Regulation 6(c), 6(d) and 7(a) – The WRDs are not contained.	Berms should be constructed around the WRDs to contain silt and runoff.
Harmony 1 – Welkom RWD	165	Regulation 7(a) – The dam is unlined. Regulation 8(a) – The dam is not fenced-off to the public and warning signs were not noted.	The dam is visible on aerial imagery that pre-dates GN R704.
Harmony 1 – ARM Vlei	166	Regulation 7(a) – The dam is unlined. Regulation 8(a) – The dam is not fenced-off to the public and warning signs were not noted.	The dam is visible on aerial imagery that pre-dates GN R704.
Harmony 1 – Masimong 4 Shaft	167	Regulation 6(c), 6(d) and 7(a) – Mud from the underground dams is compressed and stockpiled on uncontained area.	It is recommended that a bund wall is constructed around the stockpile area to contain runoff, which should report to a sump. The sump should be fitted with a pump that pumps to a dirty water facility such as the Masimong 4 Hot Water Dam.

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
			
Harmony 1 – Masimong 4 Shaft	168	Regulation 6(c), 6(d) and 7(a) – Underground waste that may potentially be radioactive is stockpiled on uncontained area. 	It is recommended that a bund wall is constructed around the stockpile area to contain runoff, which should report to a sump. The sump should be fitted with a pump that pumps to a dirty water facility such as the Masimong 4 Hot Water Dam.
Harmony 1 – Masimong 4 Shaft	169	Regulation 6(c), 6(d) and 7(a) – Water from the extractor fans ponds in this area. The water should report to Sump S68. 	It should be ensured that water from the extractor fans flows to Sump S68 to avoid ponding. This may require that the channel leading to Sump S68 is desilted, or that it may need to be extended to the extractor fan. Sump S68 should be fitted with a pump, that should pump to a dirty water facility such as the Masimong 4 Hot Water Dam.
Harmony 1 – Masimong 4 Shaft	170	Regulation 6(c), 6(d) and 7(a) – The stockpiling of waste rock for transport to the Harmony 1 Plant takes place in an uncontained area. 	It is recommended that a berm is constructed around the stockpiling area.
Harmony 1 – Masimong 5 Shaft	171	Regulation 6(c), 6(d) and 7(a) – Runoff from the concrete lined area onto bare ground at the Main Wash Bay was noted. Furthermore, the concrete lining was observed to be damaged and cracked and therefore may seep dirty water. 	A ramp should be constructed at the entrance of the Wash Bay to ensure that the Wash Bay is contained. The concrete lining of the Wash Bay should be repaired to prevent seepage.
Harmony 1 – Masimong 5 Shaft	172	Regulation 6(c), 6(d) and 7(a) – Hydrocarbon spills onto bare ground were noted at the Salvage Yard. 	Material that may leak hydrocarbons or any other hazardous substances must be placed on lined and contained areas, that report to a sump, which should pump to a dirty water facility.
Harmony 1 – Masimong 5 Shaft	173	Regulation 6(c), 6(d) and 7(a) – The stockpiling of waste rock and ore for transport to the Saaiplaas Plant takes place in an uncontained area.	It is recommended that a berm is constructed around the stockpiling and Ore Loading Area.

Infrastructure Area	Map Reference	GN R704 Non-Compliance	Recommendations
			
Harmony 1 – Masimong 5 Shaft	174	Regulation 6(c), 6(d) and 7(a) – The Masimong 5 Shaft Evaporation Dam receives dirty water from the shaft and is an unlined facility	It is unclear from historical imagery whether this facility was in place prior to June 1999 when GN R704 was enacted.
Harmony 1 – Masimong 5 Shaft	175	Regulation 6(c), 6(d) and 7(a) – The Diesel Bay bund wall was noted to have a hole in it with spills visible. Other cracks were also noted in the bund wall. 	The bund wall of the Diesel Bay should be repaired.
Harmony 1 – FFS Slimes Dams	176 – 182	Regulation 6(c), 6(d) and 7(a) – The solution trenches of the FSS1, FSS2, FSS3, FSS4, FSS6, FSS7 and FSS8 Slimes Dams are unlined.	The Slimes Dams are visible on aerial imagery that pre-dates GN R704.
Harmony 1 – WRDs	183 – 188	Regulation 6(c), 6(d) and 7(a) – The WRDs are uncontained.	Berms to contain runoff and silt are recommended around the WRDs.
Harmony 1 – Dams	189 – 197	Regulation 7(a) – Dams 12A, 12B, 12C, 13, 31, 32, 33, Wessel Pan and Unisel Shaft RWD are unlined. Regulation 8(a) – The dams are not fenced-off to the public and warning signs in prominent locations were not noted at all the dams.	The dams are visible on aerial imagery that pre-dates GN R704.
Harmony 1 – Unisel Shaft	199	Regulation 5 – The Unisel Shaft infrastructure was in the process of being demolished at the time of the site visit. According to officials, rubble will be used to backfill the shaft.	It should be ensured that hazardous material that may pollute groundwater is not placed down the shaft. It is recommended that an exemption from GN R704 is applied for.

9.4 Conceptual Stormwater Management Plan

The existing and proposed stormwater measures at the Harmony 1 Operations are shown on Figure 9-11 to Figure 9-19 and are described below. The Bambanani Shafts were not assessed as they are closed. The Unisel Shaft and associated infrastructure was in the process of being demolished at the time of the site visit.

9.4.1 Existing Stormwater Measures

The following provides a summary of the existing stormwater measures at the Harmony 1 Operations:

9.4.1.1 Harmony 1 Plant

- The plant area is mostly concrete lined;
- Dirty areas where spills may occur, such as the CIL tank area, are bunded and report to sumps that pump back into the process;
- The plant is surrounded by a concrete wall and therefore no external runoff enters the plant;
- Concrete lined channels are in place to convey dirty water to a number of sumps as well as the Surge Dam, which pump back into the process; and
- The Ore Reception Area drains to channel DC16 which reports to Sump S42.

9.4.1.2 Tshepong Shaft

- The Tshepong Shaft is mostly concrete lined.
- A number of channels and sumps that capture runoff are located around the shaft. These include:
    - Sumps S47 – S49 capture dirty water runoff from the Workshops via a number of concrete channels. S47 and S49 pump to S48 (main sump), which pumps to the Tshepong PCD;
    - Sump S50 captures runoff from the IMS Storage Area, and most likely pumps water to the nearby street;
    - Sump S51 captures runoff from a small concrete lined area and is fitted with an oil water separator. This area was previously used for mechanical services, but is now used for the cleaning of the winder riggers;
    - The HPE Workshop drains to channel CC8 which conveys water to the veld above the Tshepong Stormwater Dam;
    - Sumps S52 and S53 capture dirty runoff from the Wash Bay and pump to an unlined dirty channel (DC17). DC17 reports to channel DC20 which flows to Freddie's RWD;
    - Channel DC18 conveys runoff to Sump S54 which pumps to channel DC19. DC19 reports to channel DC20;

- Sumps S55 and S56 capture runoff from the extraction fans and pump to channel DC20;

- The bank area at the shaft is concrete lined and on a slightly raised platform, and therefore, stormwater flows away from the shaft entrance; and
- Stormwater from the parking lot and admin office area is captured in a number of stormwater drains, that conveys runoff offsite.

9.4.1.3 Phakisa Shaft

- Most of the shaft area is concrete lined;
- The bank area at the shaft is concrete lined and on a slightly raised platform, and therefore, stormwater flows away from the shaft entrance;
- The Koffer Dam receives dirty water from the Wash Bay Sump S63 as well as Sump S57 at the bank area;
- Runoff from the Fridge Plant is captured in lined concrete channels and sumps (S58 – S61), which pump water to JoJo tanks near S61. This water is recycled and reused;
- Clean channel CC10 diverts clean runoff around the shaft area;
- The RGB Engineering and Loco Storage Area are concrete lined and drain towards a drain that conveys water to channel CC10. Channel CC10 conveys water below the R70 road, from where it flows to Mimosa Pan near Odendaalsrus; and
- A number of stormwater drains are located in the parking area, that drain stormwater to Mimosa Pan.

9.4.1.4 Nyala Shaft

- The bank area at the shaft is concrete lined and on a slightly raised platform, and therefore, stormwater flows away from the shaft entrance;
- Most of the shaft area is concrete lined;
- Channel DC24 captures spills and overflows from the 3.7 Million Dam and conveys it to Masons Vlei;
- The Wash Bay is concrete lined and reports to Sump S64, which pumps water to 3.7 Million Dam;
- Sump S65 captures runoff from the Ore Loading Area; and
- Sump S66 captures runoff from the parking area.

9.4.1.5 Eland Shaft

- The Salvage Yard is concrete lined and reports to Sump S67; and
- The Eland Shaft Water Dam is concrete lined and receives dewatered groundwater from the Eland Shaft. The overflow from the dam reports to the D-Dam via a trench.

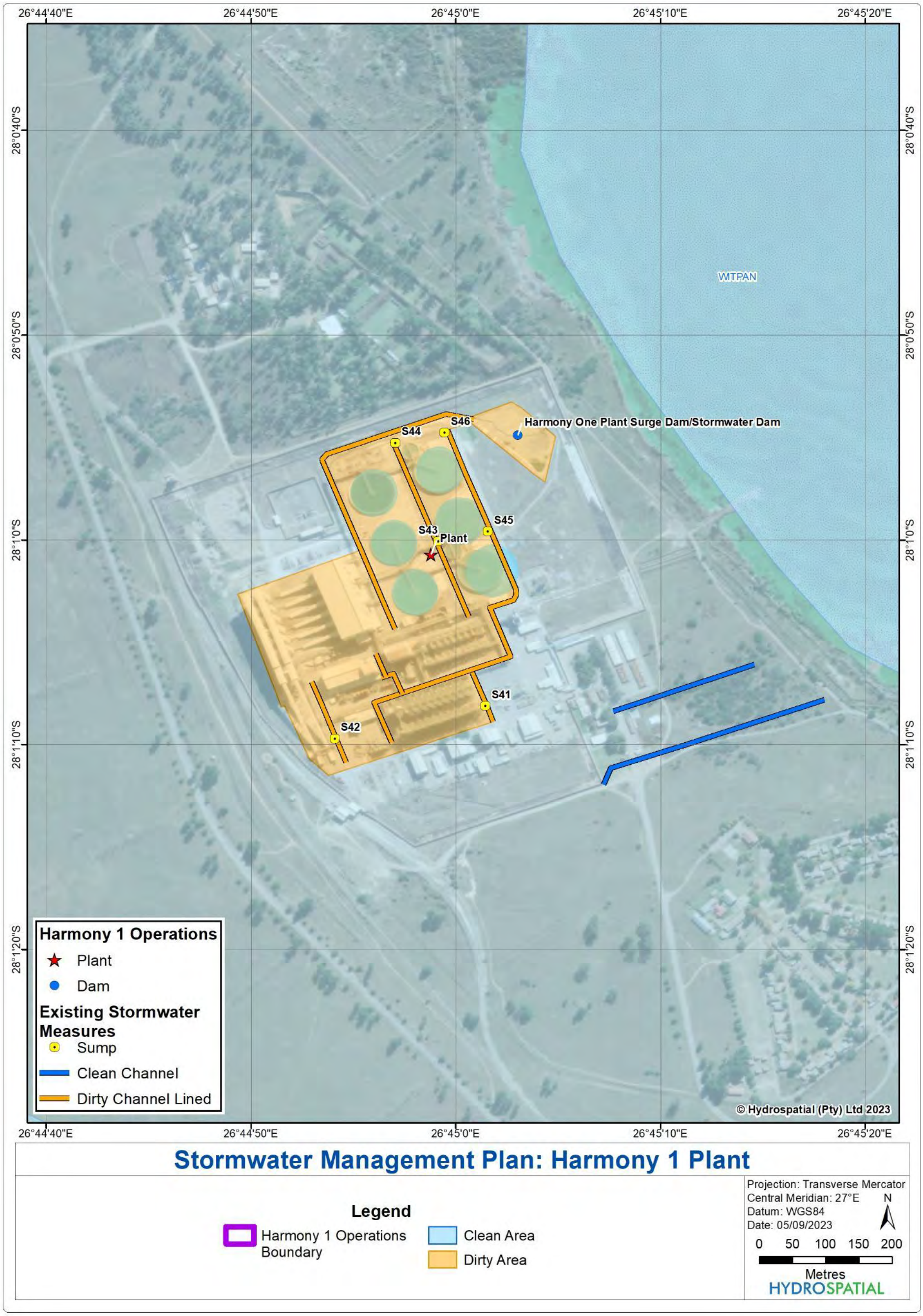


Figure 9-11: Conceptual stormwater management plan for the Harmony 1 Plant

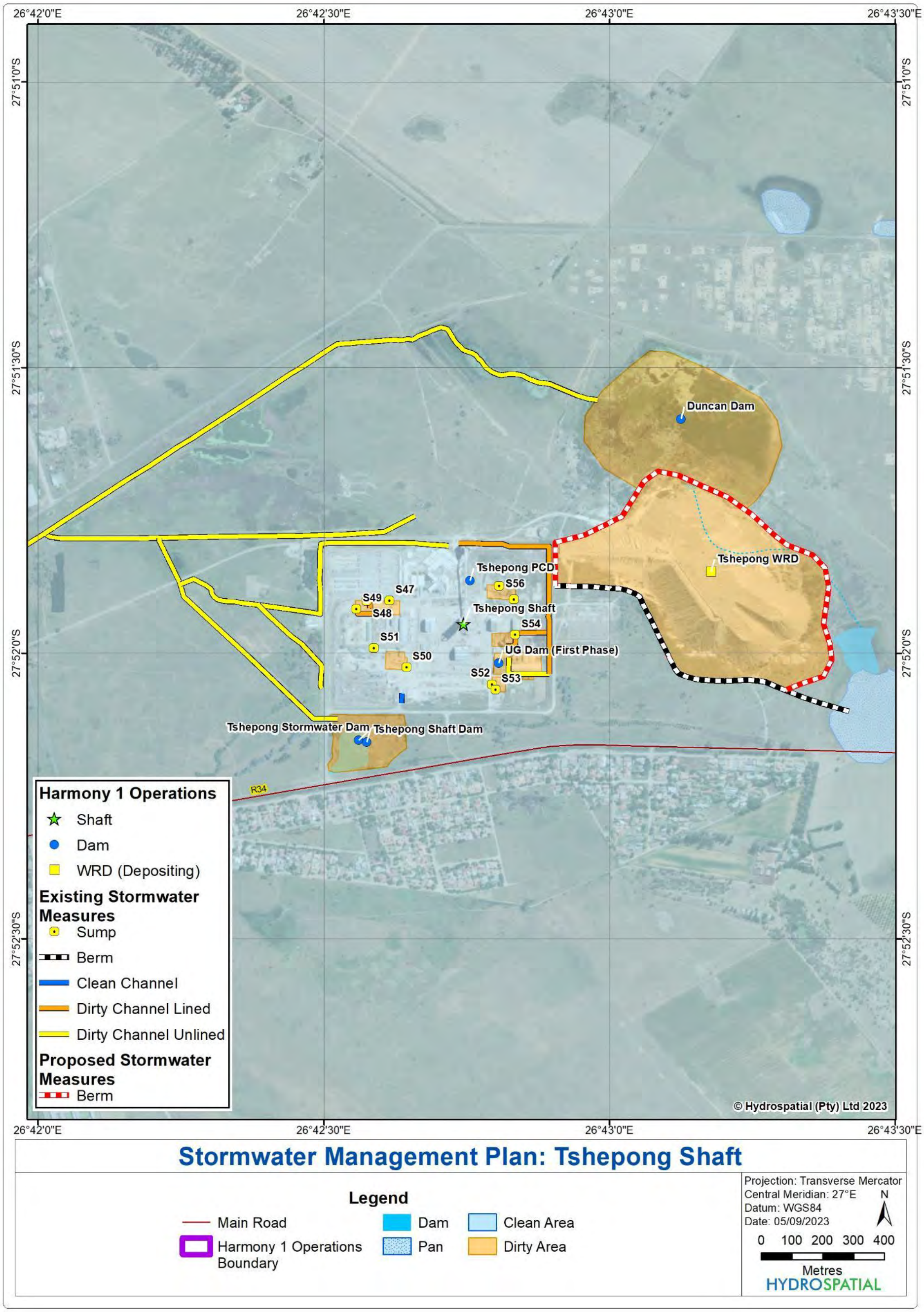


Figure 9-12: Conceptual stormwater management plan for the Tshepong Shaft

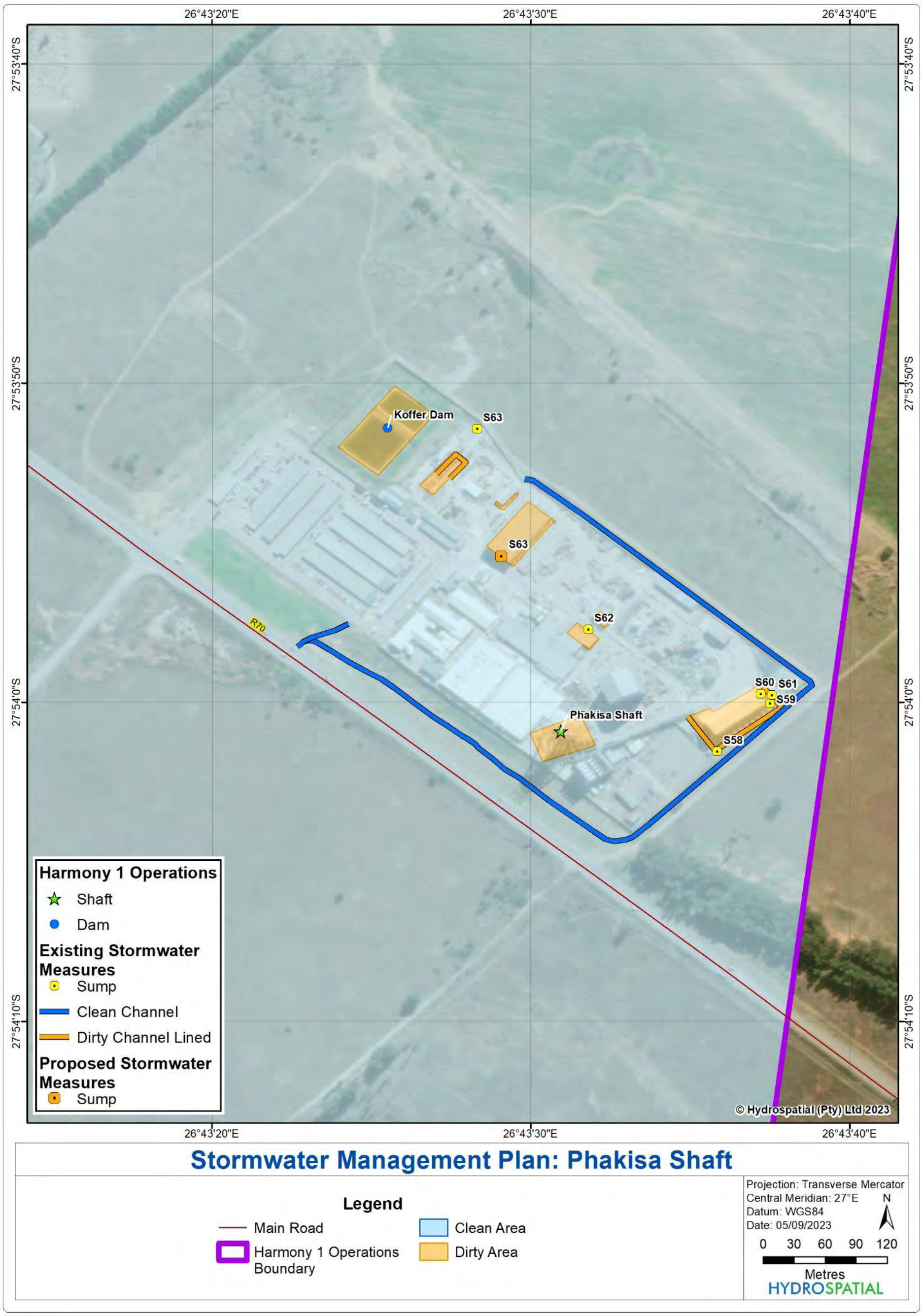


Figure 9-13: Conceptual stormwater management plan for the Phakisa Shaft

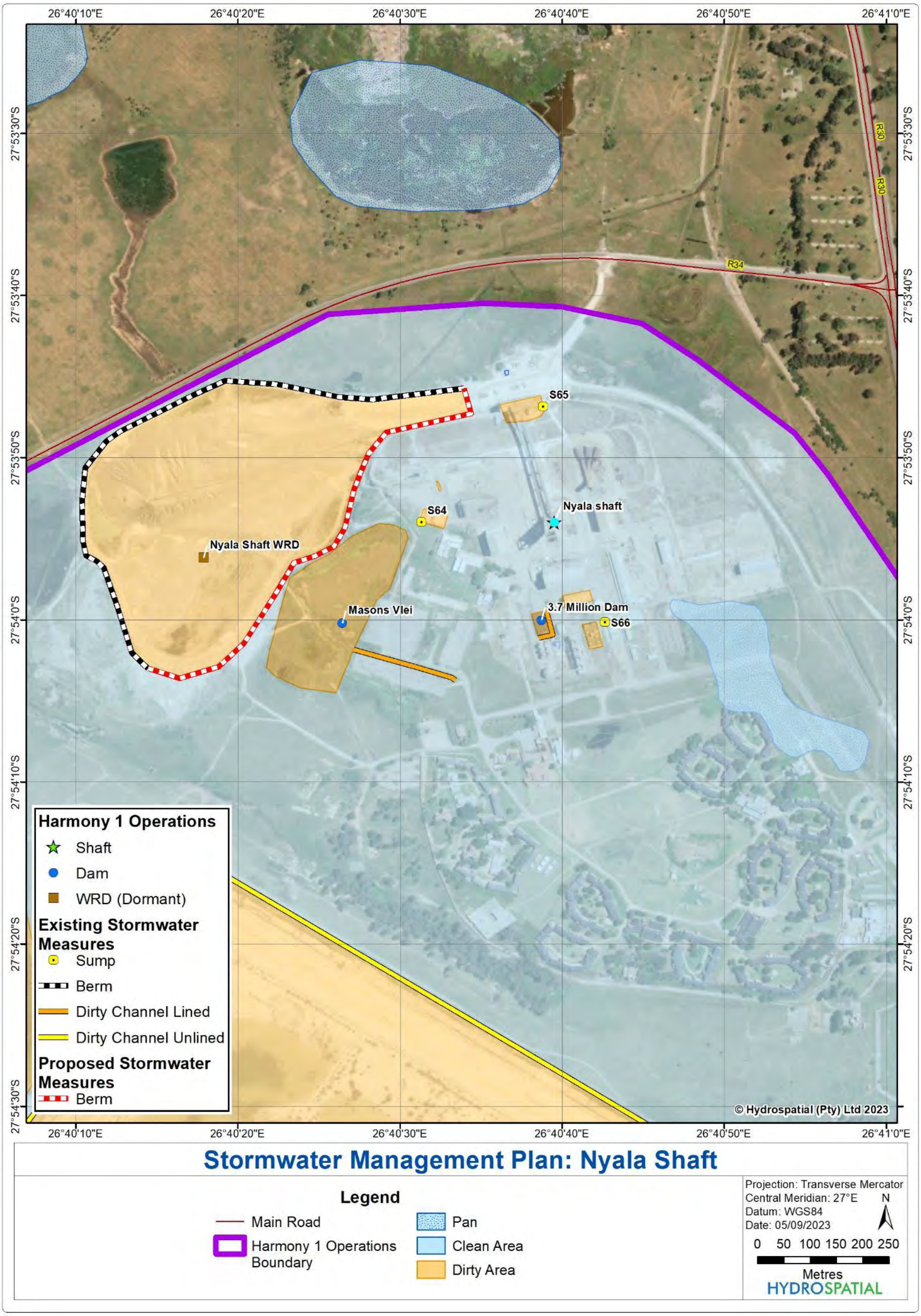


Figure 9-14: Conceptual stormwater management plan for the Nyala Shaft

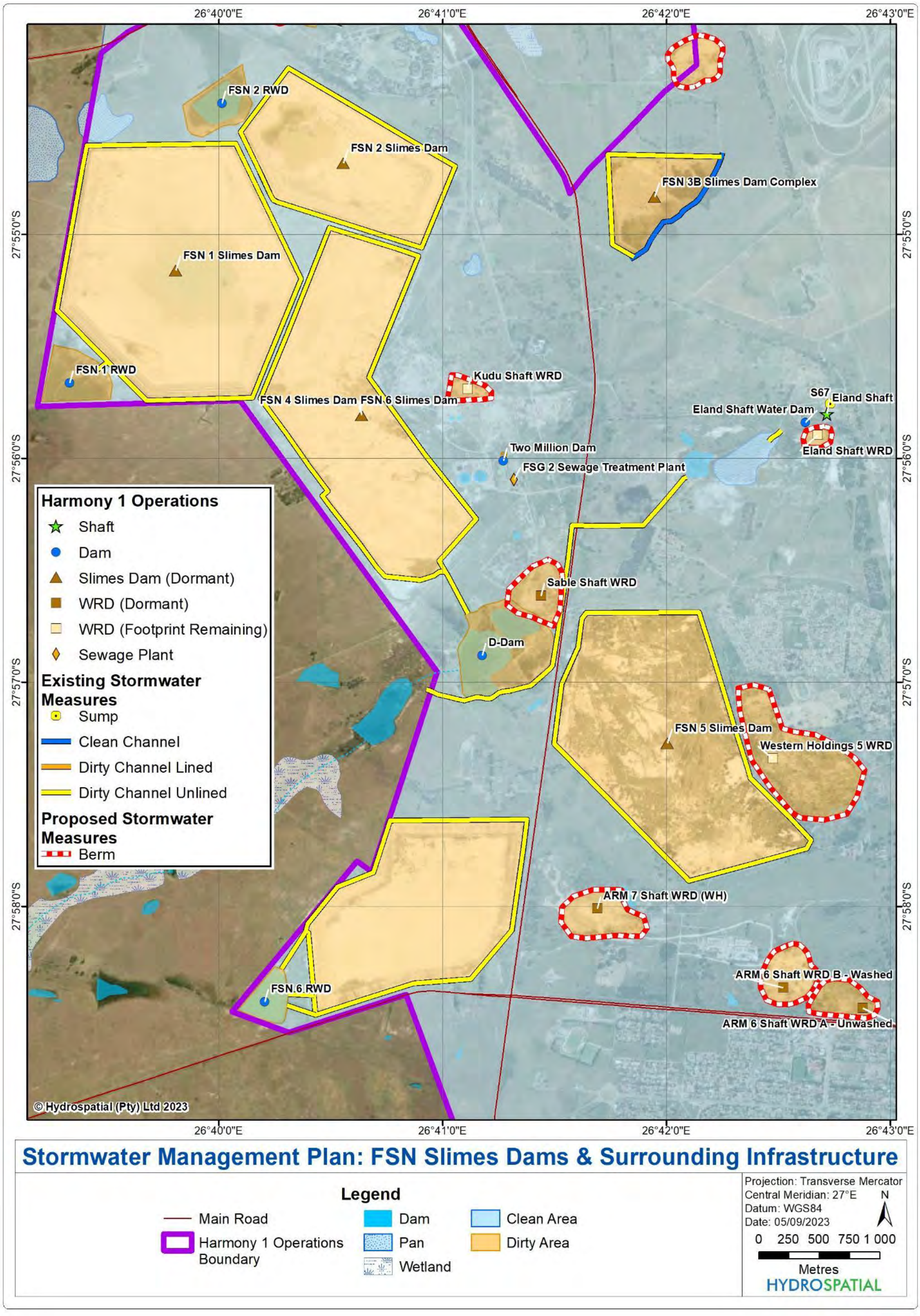


Figure 9-15: Conceptual stormwater management plan for the FSN Slimes Dams and surrounding infrastructure

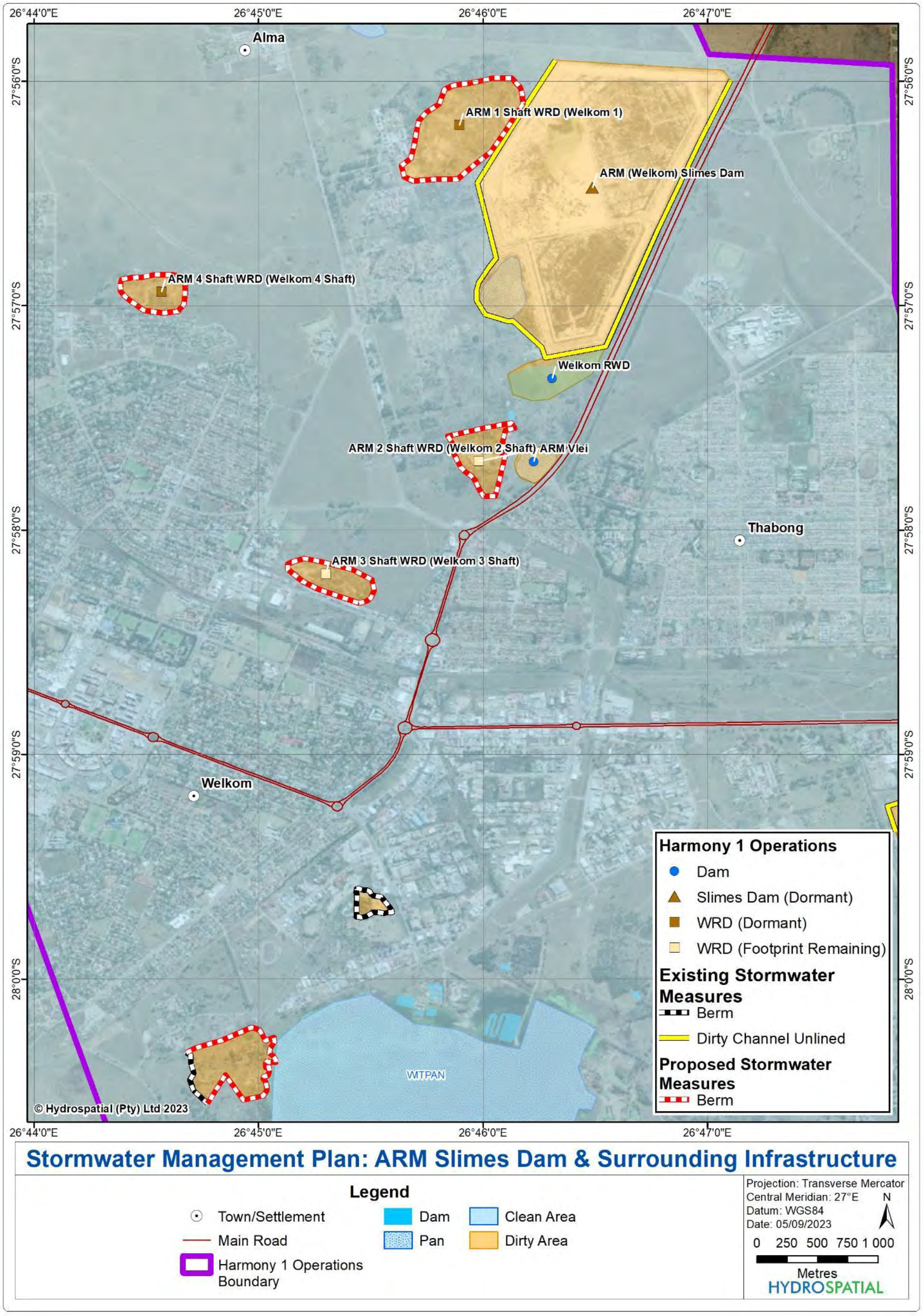


Figure 9-16: Conceptual stormwater management plan for the ARM Slimes Dam and surrounding infrastructure

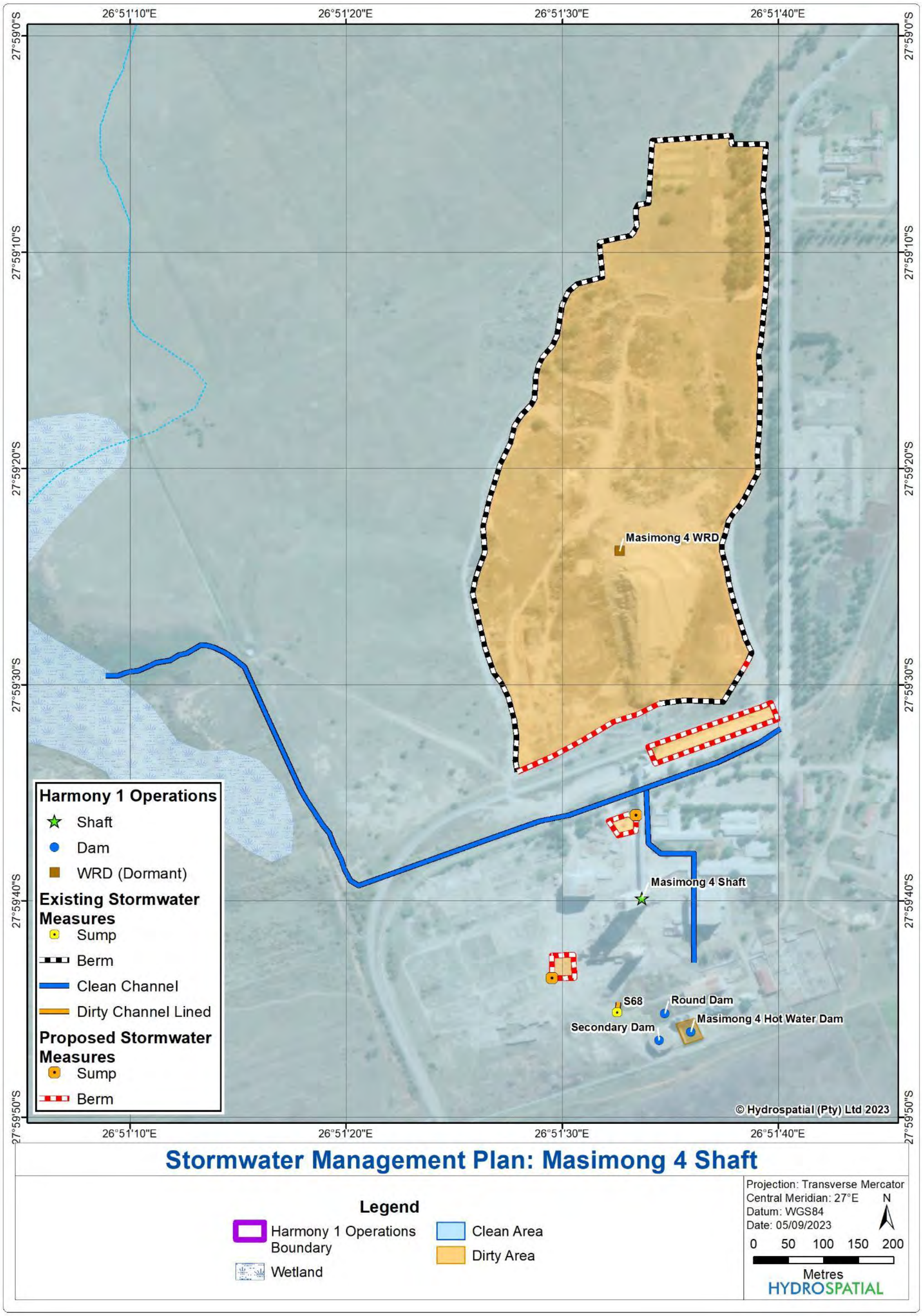


Figure 9-17: Conceptual stormwater management plan for the Masimong 4 Shaft

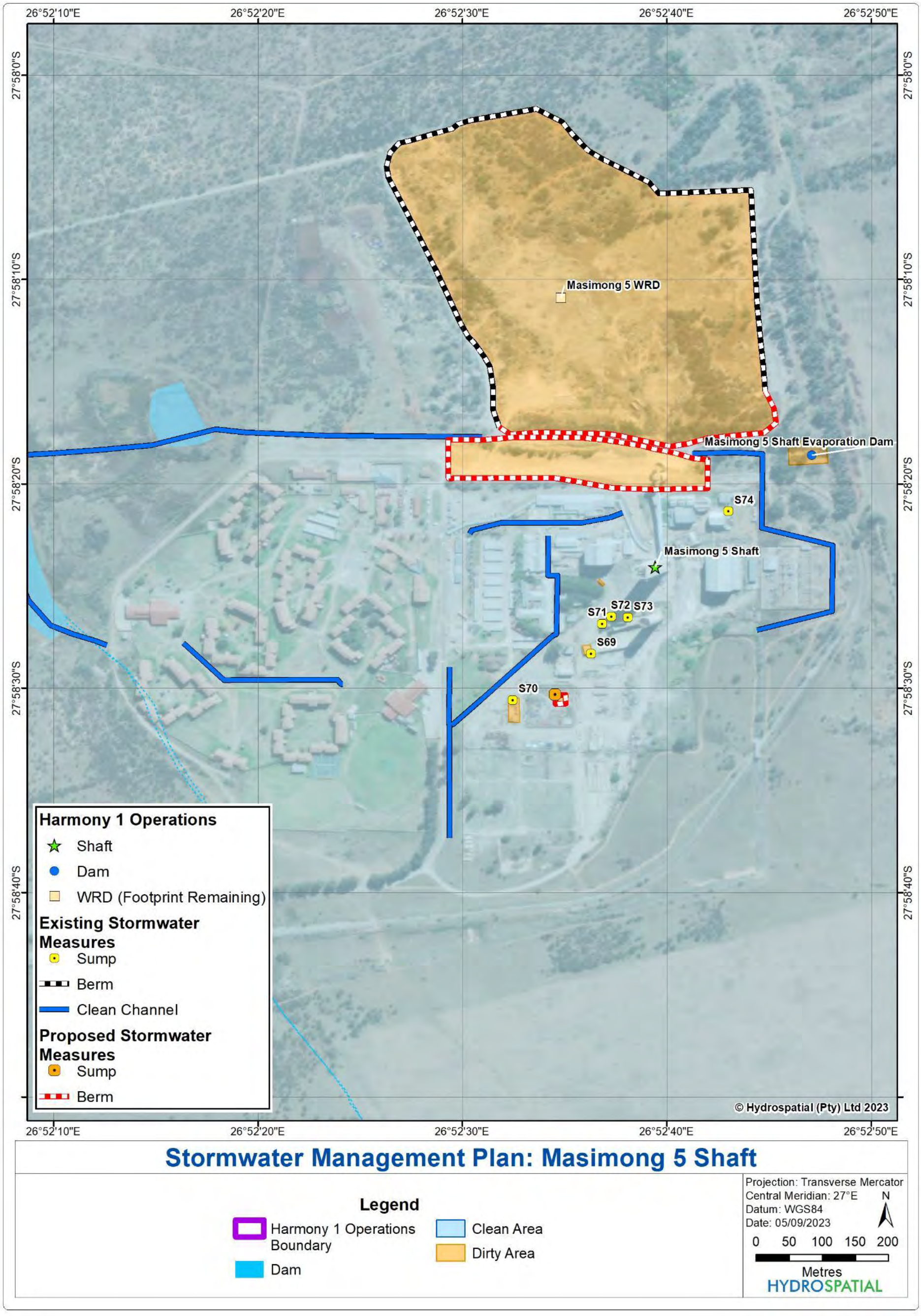


Figure 9-18: Conceptual stormwater management plan for the Masimong 5 Shaft

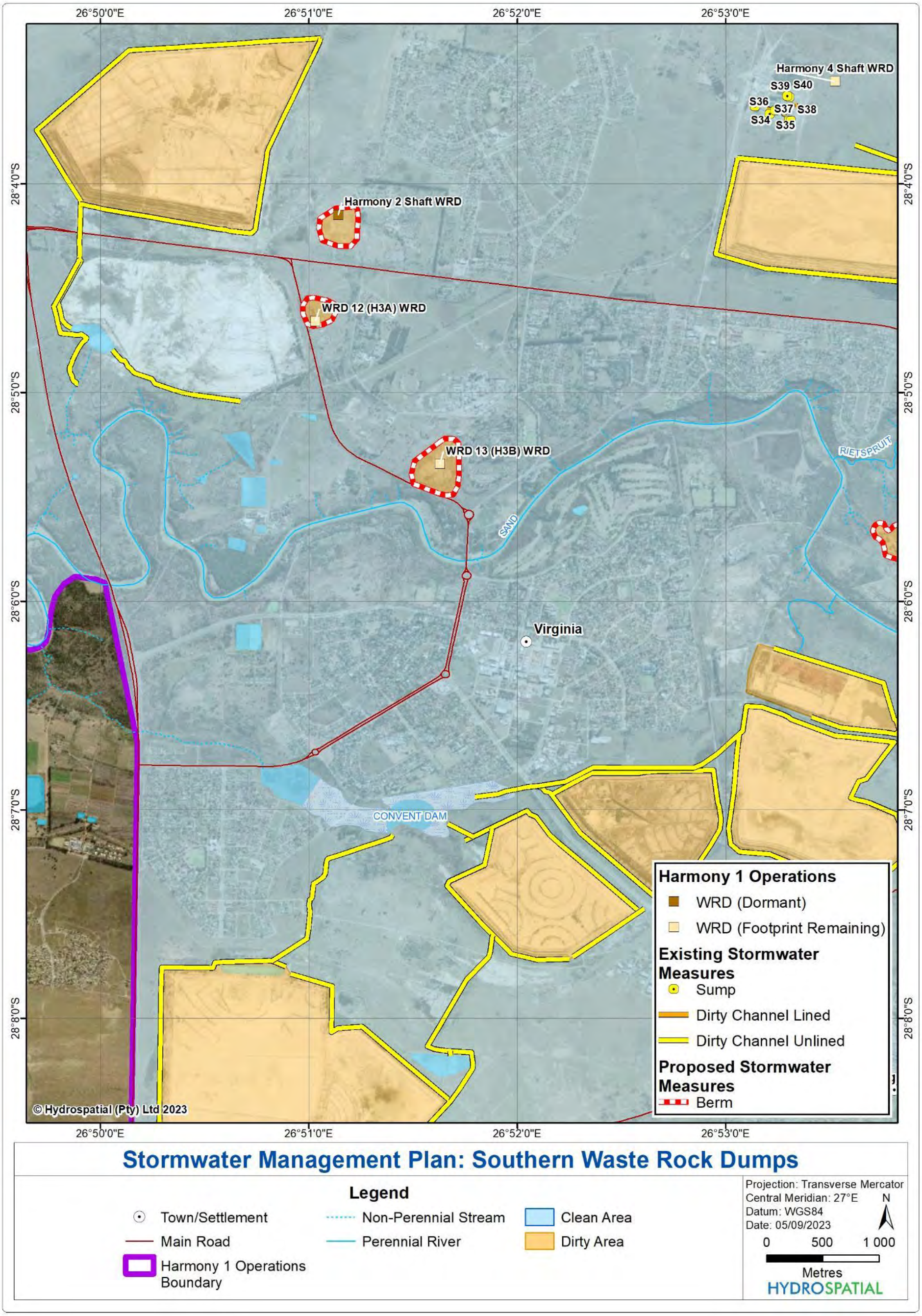


Figure 9-19: Conceptual stormwater management plan for the southern waste rock dumps

9.4.1.6 Masimong 4 Shaft

- The bank area at the shaft is concrete lined and on a slightly raised platform, and therefore, stormwater flows away from the shaft entrance;
- Most of the shaft area is concrete lined;
- Mud from the underground dams is compressed and stockpiled on a concrete lined area;
- Underground waste is stockpiled on a concrete lined area;
- Sump S68 captures runoff from the Extractor Fan;
- The Round Dam captures leaks and spills from the pipes near the Masimong 4 Hot Water Dam; and
- Channel CC11 captures runoff from around the shaft and conveys it to channel CC12 outside of the shaft that goes to Blesbokpan.

9.4.1.7 Masimong 5 Shaft

- The bank area at the shaft is concrete lined and on a slightly raised platform, and therefore, stormwater flows away from the shaft entrance;
- The TMM Wash Bay is concrete lined and bunded and reports to Sump S69 that pumps to the Main Wash Bay Sump;
- The Main Wash Bay is concrete lined and reports to Sump S70;
- Sumps S71 and S72 capture runoff from the Extraction Fans;
- All sumps report to the Main Sump S73, which pumps to the Evaporation Dam;
- Sump S74 captures runoff from the compressors and pumps it to the Evaporation Dam; and
- Clean water channels which convey runoff to Doringpan.

9.4.1.8 Slimes Dams

Unlined trenches have been constructed around the slimes dams which convey seepage and runoff to dirty water dams.

9.4.1.9 Waste Rock Dumps

Berms have been constructed around some of the WRDs to contain runoff and silt, however, majority of them do not contain berms.

9.4.2 Clean and Dirty Areas

The dirty areas at the Harmony 1 Operations include the TSFs / Slimes Dams, WRDs, RWDs, evaporation dams, plant and sections of the shafts. Dirty areas should be contained to ensure that they do not flow or seep into clean areas. The remaining areas should be managed as clean areas, which should not be contaminated by dirty areas, or flow into dirty areas. Figure 9-11 to Figure 9-19 show the clean and dirty areas at the Harmony 1 Operations.

9.4.3 Proposed Stormwater Measures and Recommendations

A summary of the proposed stormwater measures and recommendations for the Harmony 1 Operations is provided below:

9.4.3.1 Harmony 1 Plant

- It is recommended that the bunded areas, channels and sumps at the plant are inspected on a daily basis and cleaned as soon as silt begins to accumulate (preferably weekly or less); and
- The Surge Dam was heavily silted at the time of the site visit. This is an important stormwater dam and should therefore be cleared of silt more frequently.

9.4.3.2 Tshepong Shaft

- The sumps should be fitted with automatic level sensor pumps to prevent spills.
- Dirty channel DC17 should be formalised and lined;
- The Wash Bays should be desilted more frequently than is currently done, as it appears as though silt is affecting the sump pumps;
- The concrete dirty channel DC20 was noted to be damaged and needs to be repaired; and
- For areas at the shaft to be operated as clean areas, it is of outmost importance that all hydrocarbon and hazardous areas are lined and contained, and that they report to dirty water containment facilities. Hydrocarbon spills as well as any other hazardous spills at the shaft, must be cleaned up immediately for these areas to be operated as clean areas. This may require more frequent inspections and for the drivers of machinery and vehicles to be equipped with spill kits at all times.

9.4.3.3 Phakisa Shaft

- It should be ensured that hydrocarbons or any other potential hazardous materials, are not stored outside of bunded areas at the RBG Engineering and Loco Storage Area, as this area reports to the environment;
- A sump is proposed to capture dirty water from the Jig Workshop;
- The channel on the southern side of the Wash Bays needs to be formalised and concrete lined; and
- Seepage of dirty water potentially from the Change Houses and Ice Plant into clean channel CC10 should be found and prevented.

9.4.3.4 Nyala Shaft

- Seepage from the walls of the 3.7 Million Dam should be prevented by repairing the walls;
- The discharge pipe from the 3.7 Million Dam should be directed into the surrounding channel to prevent spills; and

- A berm should be constructed around the Nyala WRD and waste rock stockpiling area, to contain runoff and silt.

9.4.3.5 Eland Shaft

- A berm should be constructed around the Eland WRD o contain runoff and silt.

9.4.3.6 Masimong 4 Shaft

- It is recommended that a bund wall is constructed around the mud stockpile area as well as the underground waste storage area to contain dirty runoff. These areas should report to a sump fitted with a pump, that pumps to a dirty water facility such as the Masimong 4 Hot Water Dam;
- Runoff from the Extractor Fans should report to Sump S68 and should be prevented from ponding. Sump S68 should be fitted with a sump; and
- A berm should be constructed around the waste rock stockpiling area.

9.4.3.7 Masimong 5 Shaft

- A ramp should be constructed at the entrance to the Main Wash Bay to prevent runoff from flowing onto bare ground;
- Material and equipment that may potentially leak hydrocarbons as well as hazardous substances should be placed on a lined and contained area at the Salvage Yard; and
- A berm should be constructed around the waste rock stockpiling area.

9.4.3.8 Other Areas

- The D-Dam, FSN 1, FSN 2 and FSN 6 RWDs, were noted to be seeping. It is recommended that a paddock or trench is constructed immediately downstream of these dams, that the seepage can be captured and pumped back into the dams; and
- Berms should be constructed around the WRDs to contain runoff and silt.

In addition to the above, the recommendations provided in Table 9-3 should be implemented.

10 REFERENCES

Bezuidenhout H.,Bredenkamp G.J. and Theron G.K. 1994. Syntaxonomy of the Vegetation of the Fb Land Type in the Western Transvaal Grassland, South Africa

Gericke O.J. and du Plessis J.A. 2013. Development of a Customised Design Flood Estimation Tool to Estimate Floods in Gauged and Ungauged Catchments. Water SA Vol. 39 No. 1 January 2013.

Jones & Wagener (May 2017), *Harmony Gold Free State Operations Integrated Water and Waste Management Plan*. Report Reference: JW134/16/F141 – Rev 1, Johannesburg.

Lynch S.D. 2003. The Development of a Raster Database of Annual, Monthly and Daily Rainfall for Southern Africa. Water Research Commission (WRC) Report No. 1156/1/03.

Pitman, W.V. and Midgley, D.C. 1971. Amendments to Design Flood Manual. HRU 4/69. University of the Witwatersrand, Hydrological Research Unit . Report No 1/71. 1971.

SANRAL. 2013. The South African National Roads Agency SOC Limited (SANRAL) Drainage Manual, 6th edition.

Schmidt, E.J. and Schulze, R.E. 1987. Flood volume and peak discharge from small catchments in southern Africa, based on the SCS technique. Water Research Commission, Pretoria, WRC-TT 31/87. 164 pp.

Shangoni Management Services 2009. Avgold- Target. Environmental Management Programme.

Smithers J.C. and Schulze R.E. 2002. Design Rainfall and Flood Estimation in South Africa. WRC Project No. K5/1060.

SRK 2020a. Harmony Gold – Central Operations. Integrated Water and Waste Management Plan in Support of the Water Use Licence Application. Report Number 548500/Central WULA.

SRK 2020b. Harmony Gold – Harmony 1 Operations. Integrated Water and Waste Management Plan in Support of the Water Use Licence Application. Report Number 548500/Harmony 1 WULA.

SRK 2020c. Harmony Gold – Joel Operations. Integrated Water and Waste Management Plan in Support of the Water Use Licence Application. Report Number 548500/Joel WULA.

SRK 2020d. Harmony Gold – Saaiplaas Operations. Integrated Water and Waste Management Plan in Support of the Water Use Licence Application. Report Number 548500/Saaiplaas WULA.

SRK 2020e. Harmony Gold – Target Operations. Integrated Water and Waste Management Plan in Support of the Water Use Licence Application.

Van Bladeren D. 2005. Verification of the Proposed Standard Design Flood (SDF). SRK Consulting. Report No. 344512/1.

SRK Consulting 2020a. Harmony Gold – Central Operations. Integrated Water and Waste Management Plan in Support of the Water Use Licence Application. Report Number 548500/Central WULA.

APPENDIX A: GN R704 REGULATIONS

APPENDIX B: CURRICULUM VITAE

Appendix E: Quantity Report for September 2024 to February 2025

Appendix F: Groundwater Study

2025 Harmony Free State Operations Groundwater Flow and Mass Transport Model Update

Prepared by H Janse van Rensburg

October 2025

Although AquiSim Consulting (Pty) Ltd. exercises due care and diligence in rendering services and preparing documents, AquiSim Consulting (Pty) Ltd. accepts no liability, and the client, by receiving this document, indemnifies AquiSim Consulting (Pty) Ltd. and its directors, managers, agents and employees against all actions, claims, demands, losses, liabilities, costs, damages and expenses arising from or in connection with services rendered, directly or indirectly by AquiSim Consulting (Pty) Ltd. and by the use of the information contained in this document.

COPYWRITE WARNING

This document contains confidential and proprietary information of AquiSim Consulting (Pty) Ltd and is protected by copyright equally shared between *Harmony Gold Mining Company Limited* and AquiSim Consulting (Pty) Ltd and may not be reproduced or used without the written consent of AquiSim Consulting (Pty) Ltd, which has been obtained beforehand.

This document is prepared exclusively for *Harmony Gold Mining Company Limited* and is subject to all confidentiality, copyright and trade secrets, rules, intellectual property law and practices of South Africa.

AquiSim Consulting (Pty) Ltd

Title: 2025 Harmony Free State Operations Groundwater Flow and Mass Transport Model Update

Document Reference Number	ASC-1018F-6
Document Version Number:	Version 1.0
Date:	October 2025

Conducted on Behalf of:

Harmony Gold Mining Company Limited

P.O. Box 2
Randfontein, South Africa
1760

For Attention:

Mr John van Wyk
Environmental Manager: Free State Operations
Tel: +27 (0)18 478 6519
Cell: +27 (0)83 682 4089
Email: jvwyk@harmony.co.za

Prepared by:

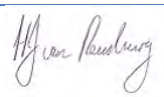
H. Janse van Rensburg PhD. Geohydrology UOFS MBL UNISA		

Offices

109 Bosduif Crescent Wierdapark x1 P.O. Box 51777 Wierdapark CENTURION 0149, South Africa Tel. No.: +27 (12) 654 0212 Fax. No.: +27 866896006 e-mail: japie@aquisim.co.za	5 Binga Place Faerie Glen Pretoria South Africa 0081 Tel. No.: +27 82 784 2023 Fax. No.: +27 866843449 e-mail: hugo@aquisim.co.za

Directors: J.J. van Blerk (Ph.D), H. Janse van Rensburg (Ph.D, MBL)

AUTHORISATION

	NAME	SIGNED	DATE
PREPARED	H. Janse van Rensburg		
Geohydrologist			
PREPARED			
Scientist			
CHECKED	M. Nieuwoudt		
Radiation Manager (Harmony)			
CHECKED			
Radiation Protection Officer			
CHECKED			
Environmental Manager			
APPROVED			
General Manager			

DISTRIBUTION

NO.	NAME	NO.	NAME
1	Harmony Gold Mining Company Limited	11	
2	Aquisim Consulting (Pty) Ltd	12	
3		13	
4		14	
5		15	
6		16	
7		17	
8		18	
9		19	
10		20	

* = Distributed via e-mail

TABLE OF CONTENTS

AUTHORISATION II

DISTRIBUTION II

TABLE OF CONTENTS III

LIST OF FIGURES VII

LIST OF TABLES XI

1 INTRODUCTION 1
1.1 Background 1
1.1.1 Structure of Operations 1
1.1.2 Potential to Generate Radioactive Material 1
1.1.3 Potential to Generate Acid Mine/Rock Drainage 2
1.2 Brief 2
1.3 Objectives of the Investigation 3
1.4 Methodology 4
1.5 Sources of Information 5

2 REGIONAL DESCRIPTION 6
2.1 Introduction 6
2.2 Locality of the Study Area 6
2.3 Rainfall, Temperature and Evaporation 6
2.3.1 Rainfall 6
2.3.2 Temperature 6
2.3.3 Evaporation 9
2.4 Topography and Drainage 10
2.4.1 The Sand River 10
2.4.2 The Sand Spruit 10
2.4.3 The Mahem Spruit 10
2.4.4 The Doring River 10
2.4.5 The Merrie Spruit 12
2.4.6 The Riet Spruit 12
2.4.7 Ultimate Receptors for the different Sub-Catchments of the Study Area. 12
2.4.8 Surface Relief 13

3 GEOLOGY OF THE STUDY AREA 14
3.1 Relevance of the Geology 14
3.2 Sequential Geology 14
3.3 Regional Surface Geology 14
3.3.1 Witwatersrand Supergroup 14
3.3.2 Ventersdorp Supergroup 14
3.3.3 Karoo Sequence 14
3.4 Structural Geology 15

4 HYDROGEOLOGY OF THE STUDY AREA 17
4.1 Available Information 17
4.2 Monitoring Borehole Positions 17
4.3 Borehole Yields 34
4.4 Groundwater Level vs. Topography 34
4.5 Depth to Water Table(s) 35
4.6 Groundwater Level Contours, Flow Directions and Groundwater Fluctuations 36
4.6.1 Groundwater Level Contours 36
4.6.2 Groundwater Flow Directions 37
4.6.3 Groundwater Fluctuations 38
4.7 Groundwater Abstraction 39
4.8 Hydraulic Tests and Aquifer Parameters 39
4.8.1 Aquifer Transmissivity 42
4.8.2 Hydraulic Conductivity 42
4.8.3 Aquifer Storativity 42
4.8.4 Hydraulic parameters for aquifer(s) in the Harmony Welkom Study area 42

5 GROUNDWATER FLOW MODEL DEVELOPMENT 44
5.1 Conceptual Model of the Aquifer System (Key Concept) 44
5.1.1 Aquifers 44
5.1.2 Type of Aquifer 45
5.1.3 Aquifer Depths 46
5.2 General Regional Conceptual Model (Golder, 2008) 47
5.3 Groundwater System Geometry 47
5.4 Area of Modelling and System Boundaries 48
5.5 Hydraulic Properties 48
5.6 Recharge, Discharge and Flow Directions 48

6 APPROACH TO NUMERICAL MODELLING 49
6.1 Introduction 49
6.2 Software Code Selection 49
6.3 Model Area 49
6.4 Mode of Flow 50
6.5 Numerical Flow Model 51
6.6 Model Boundary Conditions 51
6.6.1 Model Perimeter Boundary Conditions 51
6.6.2 Internal Model Boundaries 52
6.6.3 Model Base Boundary Condition 52
6.6.4 Model Surface Boundary Condition 52
6.7 Hydrogeological Units 52
6.8 Hydraulic Stresses 52
6.9 Calibration Approach 54

7 MODEL CONSTRUCTION, CALIBRATION AND SENSITIVITY ANALYSIS 55
7.1 Model Area and Finite Element Mesh 55
7.2 Model Perimeter and Internal Boundaries 55
7.3 Upper Model Boundary 55
7.4 Model Properties 55
7.4.1 Hydraulic Conductivity and Transmissivity 55
7.4.2 Storativity 57
7.4.3 Recharge 57
7.4.4 Evaporation 57

7.4.5 Initial Head Conditions 57
7.5 Steady State Calibration 57
7.5.1 Steady State Flow Equation 57
7.5.2 Steady State Calibration Approach 58
7.5.3 Simulation of Water Levels for State Conditions 58
7.5.4 Calibrated Hydraulic Conductivity and Transmissivity 61
7.6 Model Sensitivity Analysis 61
7.6.1 Sensitivity of the Model to K-values 61
7.6.2 Sensitivity of the Model to Recharge 65
7.7 Conclusions of Model Calibration 67

8 MASS TRANSPORT MODEL DEVELOPMENT 71
8.1 Introduction 71
8.2 Processes Controlling Contaminant Transport Migration 71
8.2.1 Advection 71
8.2.2 Hydrodynamic Dispersion 71
8.3 Mass Balance Equation 72
8.4 Numerical Mass Transport Model – Data Input 73
8.4.1 General 73
8.4.2 Input Sources and Concentration of Contaminants 73
8.4.3 Source Terms Specified in the Feflow Model 73
8.4.4 Hydraulic Conductivity 84
8.4.5 Kinematic Porosity Values 84
8.4.6 Longitudinal and Transversal Dispersivities 84
8.4.7 Hydraulic Heads 84
8.4.8 Initial Sulphate Concentrations 84
8.5 Mass Transport Transient Simulation over the period 1967-2025 Scenario 1 (Kinematic Porosity = 0.01). 84
8.5.1 Simulated Sulphate Concentration 85
8.5.2 Simulated Groundwater Velocity 85
8.6 Mass Transport Transient Simulation over the period 1967-2025 Scenario 2 (Kinematic Porosity = 0.005). 92
8.6.1 Simulated Sulphate Concentration 92
8.6.2 Simulated Groundwater Velocity 92
8.7 Mass Transport Transient Simulation over the period 1967-2025 Scenario 3 (Kinematic Porosity = 0.02). 93
8.7.1 Simulated Sulphate Concentration 93
8.7.2 Simulated Groundwater Velocity 93
8.8 Observed Temporal Sulphate Concentrations in Boreholes 96
8.9 Qualitative Assessment of Simulated Sulphate Plume Migration and Observed Sulphate Concentration Observed in Boreholes 96

9 DETAILED ANALYSIS OF CONTAMINATION IMPACT FROM THE SOURCE AREAS 102
9.1 Introduction 102
9.2 Operations in the Target Area 102
9.2.1 Location 102
9.2.2 Sources 102
9.2.3 Groundwater Elevation Contours and Flow Directions 103
9.2.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes 103
9.2.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR) 104

9.3 Operations in the Freddies 9 Shaft and Tshepong Shaft Areas 108
9.3.1 Location 108
9.3.2 Sources 108
9.3.3 Groundwater Elevation Contours and Flow Directions 108
9.3.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes 109
9.3.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR) 110
9.4 Operations in and around the Free State North (FSN) and ARM Dams 113
9.4.1 Location 113
9.4.2 Sources 113
9.4.3 Groundwater Elevation Contours and Flow Directions 113
9.4.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes 114
9.4.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR) 115
9.5 St. Helena Operations 121
9.5.1 Location 121
9.5.2 Sources 122
9.5.3 Groundwater Elevation Contours and Flow Directions 122
9.5.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes 123
9.5.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR) 125
9.6 Operations in and around the Free State Operations (FSS) Dams 128
9.6.1 Location 128
9.6.2 Sources 128
9.6.3 Groundwater Elevation Contours and Flow Directions 128
9.6.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes 131
9.6.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR) 131
9.7 Operations in and around the Brand A and D Dams; Saaiplaas SP 1,2,3,4,5A,5B and 6 Dams and Dams 21/H3 and 23/H4 136
9.7.1 Location 136
9.7.2 Sources 137
9.7.3 Groundwater Elevation Contours and Flow Directions 137
9.7.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes 138
9.7.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR) 140
9.8 Harmony Virginia Free State Dams 145
9.8.1 Location 145
9.8.2 Sources 145
9.8.3 Groundwater Elevation Contours and Flow Directions 145
9.8.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes 146
9.8.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR) 147
9.9 Operations in the Joel Mine Area 152
9.9.1 Location 152
9.9.2 Sources 152
9.9.3 Groundwater Elevation Contours and Flow Directions 153

9.9.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes 153
9.9.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR) 154

10 CONCLUSIONS 158

11 RECOMMENDATIONS 159

12 REFERENCES 160

LIST OF FIGURES

Figure 1-1 Harmony Welkom Free State Operations (Source: http:///www.harmony.co.za). 4
Figure 2-1 Regional Locality Map of the Harmony Welkom Operations in relation to the closest towns. The Mining Lease Areas are demarcated by the Red Lines. 7
Figure 2-2 Harmony Welkom Monthly Rainfall Record. 8
Figure 2-3 Harmony Welkom Monthly Average Rainfall Record 8
Figure 2-4 Harmony Welkom Annual Rainfall Record. 9
Figure 2-5 Drainage Features across the Study Area. 11
Figure 2-6 Topography Relief across the Study Area (Lease Areas in Green; Slimes Dams in Yellow). 12
Figure 3-1 Surface Geology of the Study Area. 15
Figure 4-1 Monitoring boreholes near the Target Slimes Dam and the Freddies No. 9 TSF. 17
Figure 4-2 Monitoring boreholes near the Free State Geduld (Freddies) Mine Slimes Dams. 18
Figure 4-3 Monitoring boreholes near the Brak and Dankbaar Pans, and Mahem Spruit and downstream of the Free State Geduld (Freddies) Mine. 19
Figure 4-4 Monitoring boreholes near the ARM Slimes Dam (north-northeast of Welkom) and Slimes Dams of the Pres Steyn Gold Mine (southeast of Welkom). 20
Figure 4-5 Monitoring boreholes near the Pres Steyn Gold Mine Slimes Dams (southeast of Welkom) and near the Wit Pan and Doring Pan. 21
Figure 4-6 Monitoring boreholes near the Pres Brand Gold Mine Slimes Dams and Harmony Mine Slimes Dams. 22
Figure 4-7 Monitoring boreholes in the area between Harmony Mine and the Sand River. 23
Figure 4-8 Monitoring boreholes at Joel Mine. 24
Figure 4-9 Welkom Harmony − Water Level vs. Topography. 35
Figure 4-10 Welkom Harmony − Depth to Water Level Frequency Distribution. 36
Figure 4-11 Observed Groundwater Flow Contours. 37
Figure 4-12 Groundwater Flow Directions indicated by black Arrows. 38
Figure 4-13 Long-term water level fluctuations observed at Borehole BH 123. 39
Figure 4-14 Long-term water level fluctuations observed at Borehole BH 102. 40

Figure 4-15 Long-term water level fluctuations observed at Borehole BH 103. 40

Figure 4-16 Long-term water level fluctuations observed at Borehole BH 114. 41

Figure 4-17 Long-term water level fluctuations observed at Borehole BH 117. 41

Figure 4-18 Frequency Histogram for Transmissivity Harmony Welkom using the Golder (2008) data sets. 43

Figure 6-1 Model Domain demarcated by Green Line. 50

Figure 6-2 Internal Modelling Boundaries (Dark Blue Circles) (Type I Dirichlet) Representing Drain Nodes along Rivers and Streams and on Pans. 53

Figure 7-1 Finite Element Mesh 56

Figure 7-2 Three-Dimensional View of the Finite Element Network. 57

Figure 7-3 Positions of Boreholes (indicated by the black diamonds) used for Steady State Calibrations Purposes. 59

Figure 7-4 Simulated Steady State Water Levels and Groundwater Flow Directions. 60

Figure 7-5 Scatter Plot of Simulated Versus Observed Groundwater Levels. 66

Figure 7-6 Line Plot of Simulated Versus Observed Groundwater Levels. 66

Figure 7-7 Frequency Distribution of Modelling Errors. 67

Figure 7-8 Sensitivity of Model to K-values (K-values Double the Calibrated Values). 68

Figure 7-9 Sensitivity of Model to Recharge-values (Recharge-values Half the Calibrated Values). 69

Figure 7-10 Range of Observed T-values vs. Range of Calibrated T-values used in the Model for the Hard Rock Aquifers. 69

Figure 8-1 Map showing the distribution of Storage Facilities (coloured in yellow) associated with the Free State Operations of Harmony. 74

Figure 8-2 – Source ID's (see Table 8-1) of sources situated between Allanridge and Odendaalsrus. 78

Figure 8-3 – Source ID's (see Table 8-1) of sources situated between Odendaalsrus and Welkom. 79

Figure 8-4 – Source ID's (see Table 8-1) of sources situated between Welkom and Virginia. 79

Figure 8-5 – Source ID's (see Table 8-1) of sources situated south of Virginia 80

Figure 8-6 – Source ID's (see Table 8-1) of sources situated at Joel Mine. 80

Figure 8-7 - Simulated Sulphate Plume January 1972 Scenario 1 86

Figure 8-8 - Simulated Sulphate Plume January 1977-Scenario 1. 87

Figure 8-9 - Simulated Sulphate Plume January 1987-Scenario 1. 88

Figure 8-10 - Simulated Sulphate Plume January 2007-Scenario 1. 89

Figure 8-11 - Simulated Sulphate Plume December 2025-Scenario 1. 90

Figure 8-12 - Groundwater Flow Velocity Distribution (Darcy Velocity m/d). 91

Figure 8-13 – Groundwater flow contours (black lines) superimposed on Groundwater Flow Velocity Distribution (Darcy Velocity m/d). 92

Figure 8-14 - Simulated Sulphate Plume December 2025-Scenario 2. 94

Figure 8-15 - Simulated Sulphate Plume December 2025-Scenario 3. 95

Figure 8-16 Map showing borehole water sulphate concentrations expressed in terms of the SANS (2015) livestock water standard. Yellow areas indicate source footprint positions. 100

Figure 8-17 Simulated plumes overlain on borehole water sulphate concentrations expressed in terms of the SANS (2015) livestock water standard. Source footprints are indicated by blue lines. 101

Figure 9-1 – Location of the Harmony Free State Target Operation. Sources are indicated by the red cross-hatched areas..... 102

Figure 9-2 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows..... 103

Figure 9-3 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers). 104

Figure 9-4 – Simulated mass loads to the groundwater pathway from sources. 105

Figure 9-5 - Simulated cumulative mass loads to the groundwater pathway from sources. 105

Figure 9-6 – Simulated mass loads from the groundwater pathway to receptors..... 106

Figure 9-7 – Simulated cumulative mass loads from the groundwater pathway to receptors. 106

Figure 9-8 – Location of the Harmony Free State Freddie's 9 Shaft Operation (consisting of source ID's 27/30, 28 and 29) and Tshepong Shaft Operations (consisting of source ID's 21, 99, 100 and 101). Sources are indicated by the red cross-hatched areas. 108

Figure 9-9 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows..... 109

Figure 9-10 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers). 110

Figure 9-11 – Simulated mass loads to the groundwater pathway from sources. 111

Figure 9-12 - Simulated cumulative mass loads to the groundwater pathway from sources. 111

Figure 9-13 – Simulated mass loads from the groundwater pathway to receptors..... 112

Figure 9-14 – Simulated cumulative mass loads from the groundwater pathway to receptors..... 112

Figure 9-15 – Location of the Harmony Free State North (FSN) and ARM Operations and Surrounding sources. Sources are indicated by the red cross-hatched areas. 113

Figure 9-16 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows. 114

Figure 9-17 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers). 115

Figure 9-18 – Simulated mass loads to the groundwater pathway from FSN sources..... 116

Figure 9-19 - Simulated cumulative mass loads to the groundwater pathway from FSN sources. 116

Figure 9-20 – Simulated mass loads to the groundwater pathway from ARM sources. 117

Figure 9-21 - Simulated cumulative mass loads to the groundwater pathway from ARM sources. 117

Figure 9-22 – Simulated mass loads to the groundwater pathway from FSN other sources. 118

Figure 9-23 - Simulated cumulative mass loads to the groundwater pathway from FSN other sources. 118

Figure 9-24 – Simulated mass loads from the groundwater pathway to receptors..... 119

Figure 9-25 – Simulated cumulative mass loads from the groundwater pathway to receptors..... 119

Figure 9-26 – Location of the Harmony Free State St. Helena Operation. Sources are indicated by the red cross-hatched areas. 121

Figure 9-27 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows. 123

Figure 9-28 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers). 124

Figure 9-29 – Simulated mass loads to the groundwater pathway from sources. 126

Figure 9-30 - Simulated cumulative mass loads to the groundwater pathway from sources. 126

Figure 9-31 – Simulated mass loads from the groundwater pathway to receptors. 127

Figure 9-32 – Simulated cumulative mass loads from the groundwater pathway to receptors. 127

Figure 9-33 – Location of the Harmony Free State Operation (FSS). Sources are indicated by the red cross-hatched areas. 129

Figure 9-34 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows. 130

Figure 9-35 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers). 132

Figure 9-36 – Simulated mass loads to the groundwater pathway from FSS sources. 133

Figure 9-37 - Simulated cumulative mass loads to the groundwater pathway from FSS sources. 133

Figure 9-38 – Simulated mass loads to the groundwater pathway from FSS Other sources. 134

Figure 9-39 - Simulated cumulative mass loads to the groundwater pathway from FSS Other sources. 134

Figure 9-40 – Simulated mass loads from the groundwater pathway to receptors. 135

Figure 9-41 – Simulated cumulative mass loads from the groundwater pathway to receptors. 135

Figure 9-42 – Location of the Harmony Free State Brand A and D Dams; Saaiplaas SP 1,2,3,4,5A,5B and 6 Dams and Dams 21/H3 and 23/H4 and Surrounding sources. Sources are indicated by the red cross-hatched areas. 136

Figure 9-43 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows. 138

Figure 9-44 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers). 139

Figure 9-45 – Simulated mass loads to the groundwater pathway from Brand sources. 141

Figure 9-46 - Simulated cumulative mass loads to the groundwater pathway from Brand sources. 141

Figure 9-47 – Simulated mass loads to the groundwater pathway from Saaiplaas sources. 142

Figure 9-48 - Simulated cumulative mass loads to the groundwater pathway from Saaiplaas sources. 142

Figure 9-49 – Simulated mass loads to the groundwater pathway from 21/H3 & 23/H4 sources. 143

Figure 9-50 - Simulated cumulative mass loads to the groundwater pathway from 21/H3 & 23/H4 sources. 143

Figure 9-51 – Simulated mass loads from the groundwater pathway to receptors. 144

Figure 9-52 – Simulated cumulative mass loads from the groundwater pathway to receptors. 144

Figure 9-53 – Location of the Harmony Virginia Free State Dams; No. 30A, 30B, 31, 32, 33A, 33B, 34A and 34B as well as Calcine Dams No. 25 and No.27. Sources are indicated by the red cross-hatched areas. 145

Figure 9-54 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows. 146

Figure 9-55 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers). 147

Figure 9-56 – Simulated mass loads to the groundwater pathway from Calcine sources and Convent Dams. 149

Figure 9-57 - Simulated cumulative mass loads to the groundwater pathway from Calcine sources and Convent Dams. 149

Figure 9-58 – Simulated mass loads to the groundwater pathway from Dams No. 30A, 30B, 31 and 32. 150

Figure 9-59 - Simulated cumulative mass loads to the groundwater pathway from Dams No. 30A, 30B, 31 and 32. 150

Figure 9-60 – Simulated mass loads to the groundwater pathway from Dams No. 33A, 33B, 34A and 34 B. 151

Figure 9-61 - Simulated cumulative mass loads to the groundwater pathway from Dams No. 33A, 33B, 34A and 34 B. 151

Figure 9-62 – Location of the Joel Mine Operation. Sources are indicated by the red cross-hatched areas. 152

Figure 9-63 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows. 153

Figure 9-64 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers). 154

Figure 9-65 – Simulated mass loads to the groundwater pathway from sources. 155

Figure 9-66 - Simulated cumulative mass loads to the groundwater pathway from sources. 155

Figure 9-67 – Simulated mass loads from the groundwater pathway to receptors. 156

Figure 9-68 – Simulated cumulative mass loads from the groundwater pathway to receptors. 156

LIST OF TABLES

Table 2-1 Harmony Welkom Monthly Average Rainfall Record 9

Table 2-2 Temperature Statistics for the Welkom Area. 9

Table 4-1 Harmony Welkom Monitoring Borehole Coordinates. 24

Table 4-2 Water levels for monitoring boreholes. 31

Table 4-3 Borehole Yields Encountered in the Welkom Area 34

Table 4-4 Transmissivity values analysed from field data sets obtained from Golder (2008). 42

Table 4-5 Summary of pump tests and estimated aquifer parameters (Verbatim from Golder, 2008). 43

Table 5-1 Summary of boreholes drilled in the Beaufort and Ecca Groups. 46

Table 7-1 Steady State Calibration Measures for Steady State Model. 61

Table 7-2 Calibrated Hydraulic Conductivity and Transmissivity. 67

Table 8-1 Storage Facilities associated with the Free State Operations, showing their ID's and their Purpose/Description 75

Table 8-2 – Harmony Free State Operations assumed source terms. 81

Table 8-3 Livestock Water Standard for Sulphate according to the SANS (2015). 96

Table 8-4 Representative Livestock Water Class (SANS, 2015) assigned at the monitoring boreholes 97

Table 9-1 – Target Operations source description. 103

Table 9-2 – Freddie's 9 Shaft and Tshepong Shaft Operations source description. 108

Table 9-3 – Harmony Free State North (FSN) and ARM Operations and Surrounding sources source description. 114

Table 9-4 – St. Helena Operations source description. 122

Table 9-5 – Harmony Free State Operations (FSS) source description. 128

Table 9-6 – Harmony Free State Brand A and D Dams; Saaiplaas SP 1,2,3,4,5A,5B and 6 Dams and Dams 21/H3 and 23/H4 source description. 137

Table 9-7 – Harmony Virginia Free State Dams source description. 146

Table 9-8 – Joel Mine Operations source description. 152

1 Introduction

1.1 Background

1.1.1 Structure of Operations

Harmony Gold Mining Company Limited (Harmony) has an international diversified portfolio of gold mining projects in South Africa, Papua New Guinea and Australia. Harmony's operating structure principally comprises two reporting entities represented by South African Operations and International Operations.

Harmony operates in South Africa, Papua New Guinea and Australia. The company has nine underground mines, one open pit mine and several surface operations in South Africa.

In Papua New Guinea, it has Hidden Valley, an open-pit gold and silver mine and a 50% interest in the Morobe Mining Joint Venture, which includes the Golpu project and extensive exploration tenements. Outside the joint venture, Harmony's own exploration portfolio focuses principally on highly prospective areas in Papua New Guinea.

In Australia they run the Eva Copper Mine Project. The Eva Copper Mine project is an iron oxide copper gold resource poised to become the largest copper mine in Northwest Queensland, Australia.

Harmony's Free State Operations consist of:

- Bambanani Mine near Welkom. It has two surface shafts (East and West).
- Joel Mine situated on the southern edge of the Witwatersrand basin. It has two surface shafts North and South.
- Masimong Mine near Welkom (5 Shaft-operational and 4 Shaft-ventilation).
- Phakisa Mine (Phakisa Shaft and Nyala Shaft).
- Target 1 Mine (consists of one primary underground mine).
- Tshepong Mine.
- Unisel Mine and
- Phoenix tailings retreatment operations.

South African Operations are sub-divided into eight reporting entities: Free Gold Operations, Harmony Free State Operations, Welkom Operations, West Wits Operations including Doornkop JV, Kusasalethu (previously known as Elandsrand and Deelkraal), and Kalgold Operations. Through their various operations, Harmony has made significant economic contributions to the provinces of South Africa where they are located, through job creation and stimulation of secondary services and industry.

1.1.2 Potential to Generate Radioactive Material

Gold mining and processing operations are known to be responsible for various environmental disturbances. The gold bearing reefs of the Free State Goldfields are associated with naturally occurring radionuclides such as uranium, thorium and radium. The Welkom Operations, which extract gold bearing ore from the gold bearing reefs (including the Basal Reef, Leader Reef, B Reef, A Reef, Beatrix Reef and Elsburg Reefs), thus have the potential to generate mine residue and other materials that contains naturally occurring radionuclides, generally referred to as naturally occurring radioactive material or NORM.

The protection of human health and the environment from the adverse effect of radiation exposure to NORM is regulated by national legislation. The national legislation is enforced by the National

Nuclear Regulator (NNR), a statutory body responsible for regulating the nuclear industry, but also NORM associated with the mining and mineral processing industry. Harmony holds a Certificate of Registration (CoR-58) issued by the NNR for the Welkom Operations.

1.1.3 Potential to Generate Acid Mine/Rock Drainage

Gold mining operations are further known to contribute to acid mine/rock drainage (AMD). Pyrite, a mineral closely associated with gold-bearing strata is by far the greatest contributor to acid mine/rock drainage. The mineral pyrite (FeS_2) and other sulphur containing minerals are common to gold mines. Mining gold inevitably involves exposing these pyritic materials to oxygen and water. In the deep gold mines, these materials are exposed in the voids created by the mining process. They also are brought to the surface as an unwanted waste product along with the gold, where they and other unwanted materials were separated from the gold and historically put in huge refuge piles known as tailings storage facilities (TSF's), waste rock dumps (WRD's) and return water dams (RWD's). Here too the pyritic materials were exposed to oxygen and water. Wherever pyrite can come into contact with oxygen and water a potential problem exists. This trio of pyrite, oxygen and water causes in the formation of AMD. TSFs and waste rock dumps can never be maintained in a completely reducing environment. It logically follows that there will be long term water contamination risks. This water has a low pH and a high acidity and contains toxic and radioactive heavy metals. Production of AMD may continue for many years after mines are closed and TSFs decommissioned. The Harmony Welkom Operation thus has the potential to generate AMD from its tailing's storage facilities and waste rock dumps.

1.2 Brief

AquiSim Consulting (Pty) Ltd was appointed by Harmony to establish a preliminary groundwater flow and mass transport model to simulate groundwater flow and mass transport through the aquifers within which the Harmony Welkom Operation functions during 2012 (Aquisim, 2012). Such model(s) can address aspects related to the risks that both radioactive material and AMD pose to groundwater. Since the model was established in 2012, Harmony collected monitoring information over the period 2012-2025 pertaining to water quality and water levels which is now used to update the groundwater model.

Note that for this report, the investigation only considers the migration of an inorganic substance (in this case sulphate). Should the need arise at a later stage, the flow model, which is calibrated during this investigation, may easily be expanded into a transport model to simulate the migration of radionuclides.

It would further address groundwater management aspects that could form part of the process of developing an Integrated Water and Waste Management Plan (IWWMP) of the mine's activities. An IWWMP needs to comply with the water quality management policy of DWAF and all other relevant legislation, most importantly the National Water Act, 1998 (Act 36 of 1998). Tools most relevant to provide guidance with regards to groundwater management and the development of an IWWMP is a numerical flow and mass transport model for the area under investigation. This report has the focus of considering the impact of all the Harmony Welkom Facilities on the groundwater regime. These include the facilities from the following operations:

- Bambanani.
- Joel.
- Masimong.
- Phakisa.

- Target.
- Tshepong.
- Unisel.
- Phoenix.
- Other Surface Sources.

A layout of the Harmony Free State Operations is shown in Figure 1-1. It was a requirement of Harmony that the model constructed should encompass all the above operation's Tailings Storage Facilities (TSF's), Return Water Dams (RWD's) and Waste Rock Dumps (WRD's). A groundwater flow model was thus be developed encompassing all the indicated Harmony facilities above including a mass transport model for each of the facilities. This document describes the desk study, data collection and evaluation phase, the modelling methodology applied, development of the conceptual aquifer model, numerical model and model calibration and finally the application of the model to accomplish the objectives of the study.

1.3 Objectives of the Investigation

The objectives of the study are to:

- Develop and update a conceptual model for the Harmony Operations in the Welkom Area characterising (a) groundwater flow and the interrelationship between local aquifers, (b) areas of groundwater recharge and discharge, and (c) the depth to the water table. The conceptual model must successfully incorporate the influence of regional structural features on groundwater movement, including the role of fracture zones acting as preferential groundwater flow paths.
- Develop and calibrate the numerical groundwater model quantifying the elements of the conceptual model listed above based on existing information up to 2025.
- Apply the numerical groundwater model to calculate the impact of current and anticipated activities on groundwater flow, aquifer recharge and discharge, and the depth of the water table.
- Apply the numerical model to calculate the probable spatial extent of pollution migration plumes from significant pollution sources identified. All existing contamination facilities and activities must be considered in an integrated manner, and where known, future facilities and activities.
- Develop recommendations to address any shortcomings and data knowledge gaps that need to be addressed to improve on the future calibration of the groundwater model and to verify the long-term predictions made in terms of quality and flow.
- For Harmony Free State Operations to own, on completion of this project, a calibrated groundwater flow model/contaminant mass transport model which can be used to ascertain the groundwater impacts of future development scenarios or general groundwater management across the region.

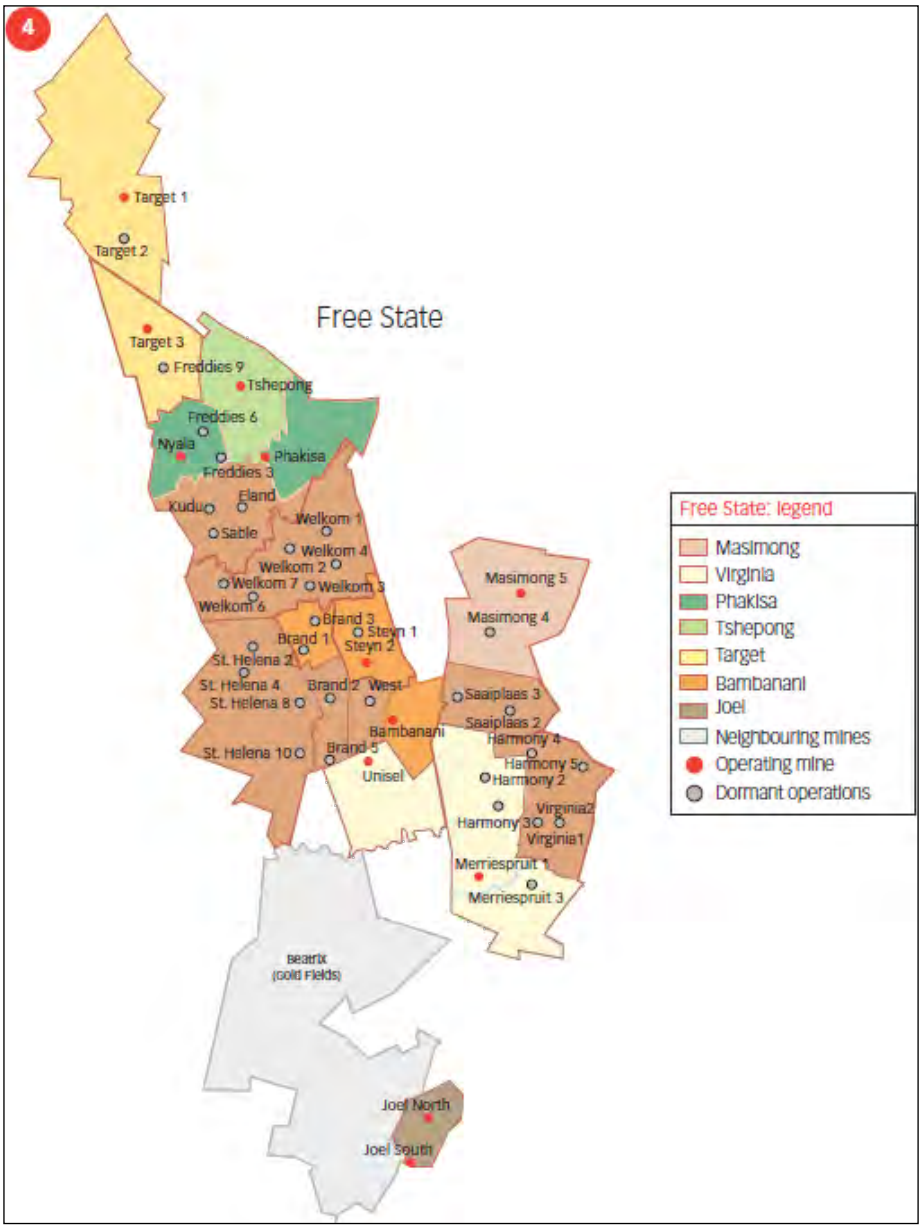


Figure 1-1 Harmony Welkom Free State Operations (Source: http:///www.harmony.co.za).

1.4 Methodology

In order to achieve the objectives of the study the following methodology was adopted.

- A monitoring data collection and evaluation phase (using the data over the period 2012– 2025).
- The review of the hydrogeological conceptual model for the area.
- Review the Construction and calibration of a groundwater flow model, which accurately describes groundwater flow through the aquifer system(s).
- Review the Construction and calibration of a mass transport model utilising source and seepage terms for selected chemical constituents emanating from the potential contamination sources which might pose a potential threat to groundwater.

- Using the model, determine the impact of contaminated seepage emanating from the potential contamination sources on the hydrogeology of the area.

1.5 Sources of Information

The following reports and information sources form the basis of this investigation:

- Electronic spreadsheet files depicting borehole chemistry monitoring results for boreholes across the Harmony Welkom Area.
- Electronic spreadsheet files depicting borehole water level fluctuations for boreholes across the Harmony Welkom Area.
- Electronic files depicting spatial infrastructure of the Harmony Welkom Area.
- Electronic Data files from the Rison Groundwater Consulting Study conducted on behalf of Golder Associates Africa: "Harmony Tailings Remining EIA – Phase 1 Groundwater Report" 2008.
- Golder Associates Africa Report: Harmony Tailings Remining EIA – Phase 1 Groundwater Report. Report No. 8788/11368/16/G. 2008.
- Groundwater Complete Report: Harmony Gold Mining Company: Groundwater Impact Study for proposed new Uranium Treatment Plant, July 2009.
- Topographical information covering a 90m grid pattern sourced from 90m-grid topographical data obtained from the USGS Shuttle Radar Topography Mission (SRTM) which was a joint venture between NASA and the NGA (National Geospatial-Intelligence Agency.
- Spatial geological information sourced from the 1:250 000 geological map sheet available for the area (2726 Kroonstad).
- Spatial geological information sourced from the 1:250 000 geological map sheet available for the area (2826 Winburg).

2 Regional Description

2.1 Introduction

The groundwater flow modelling depends on the physical properties of the site. For a numerical model to be relevant as a predictive tool, it is necessary to integrate the physical geometry and properties of the site into the model. Controlling factors are the topography and relief, surface hydrology and rainfall, geology, as well as the properties of the aquifer system.

2.2 Locality of the Study Area

Harmony's Free State operations are located on the south-western corner of the Witwatersrand Basin, between the towns of Allanridge, Welkom, Theunissen and Virginia. The bulk of the Welkom Operations of Harmony is situated between the towns of Allanridge in the north and Virginia in the south (Figure 2-1). The most southerly operation of Harmony (Joel Mine) is situated 19 kilometres to the south-southwest of the town of Virginia. The Welkom Operations cover a vast area with the distance between the Target Operation (furthest to the north) and the Joel Operation (furthest to the south) 60 kilometres apart.

The total mining lease areas of the Harmony Welkom Operations cover an area of approximately 56600 hectares (566 km^2).

2.3 Rainfall, Temperature and Evaporation

2.3.1 Rainfall

Precipitation is important to groundwater studies since it provides the mechanism that may lead to subsurface infiltration (groundwater recharge). The monthly rainfall figures for Harmony Welkom as measured at the Environmental Office over the period 1985-2024 are presented in Figure 2-2. The average monthly rainfall is presented in Figure 2-3 and Table 2-1. Rainfall occurs predominantly in the summer months, typically from October to April. Average rainfall for the months November to March is between 80 and 90 mm for each of these months.

The annual rainfall for Welkom over the period 1985-2024 is presented in Figure 2-4. The average annual total amounts to 570 mm/a.

2.3.2 Temperature

Temperatures show large daily and seasonal variations. Temperature statistics for the Welkom area, as tabulated in the Climate of South Africa (WB40), are listed in Table 1. Mean temperatures reach a maximum in December/January and a minimum in June/July. The period during which frost can be expected lasts about 100 days (June to August). The winds in the region are usually north-westerly and reach their maximum speed in the afternoon.

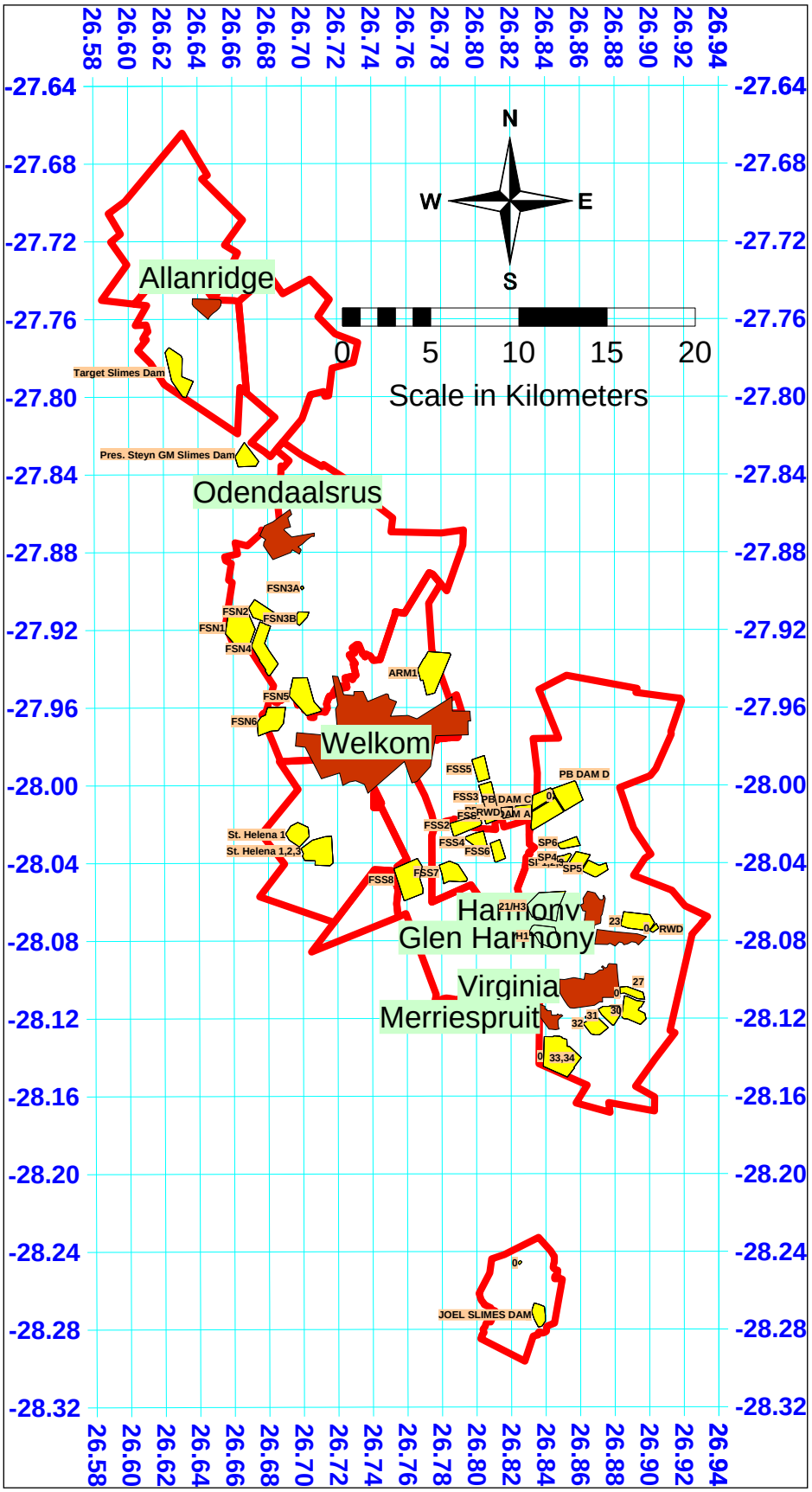


Figure 2-1 Regional Locality Map of the Harmony Welkom Operations in relation to the closest towns. The Mining Lease Areas are demarcated by the Red Lines.

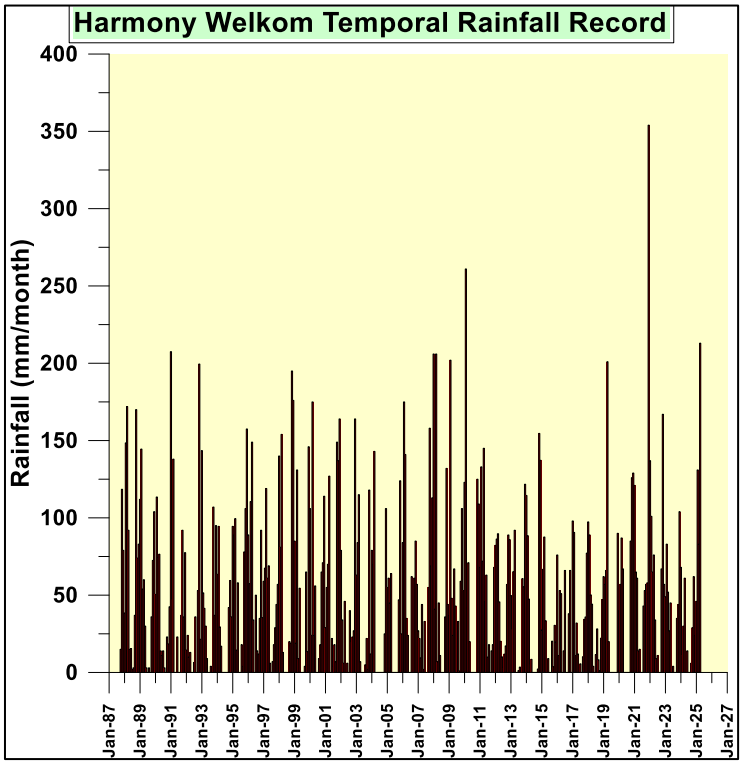


Figure 2-2 Harmony Welkom Monthly Rainfall Record.

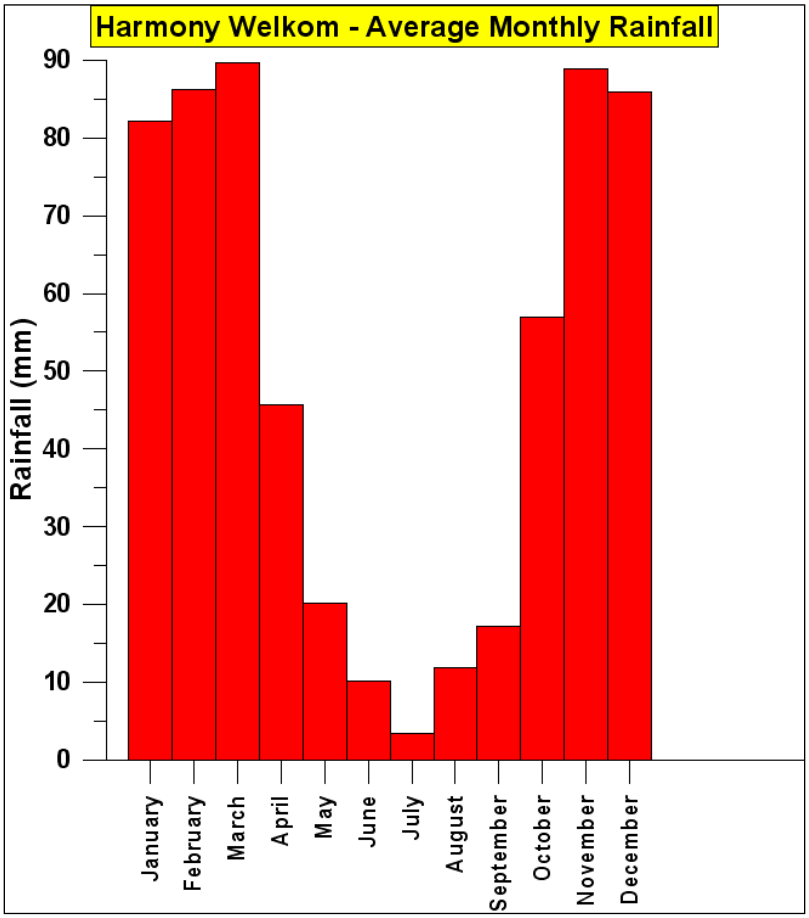


Figure 2-3 Harmony Welkom Monthly Average Rainfall Record.

Table 2-1 Harmony Welkom Monthly Average Rainfall Record.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
82	86	90	46	20	10	3	12	17	57	89	86

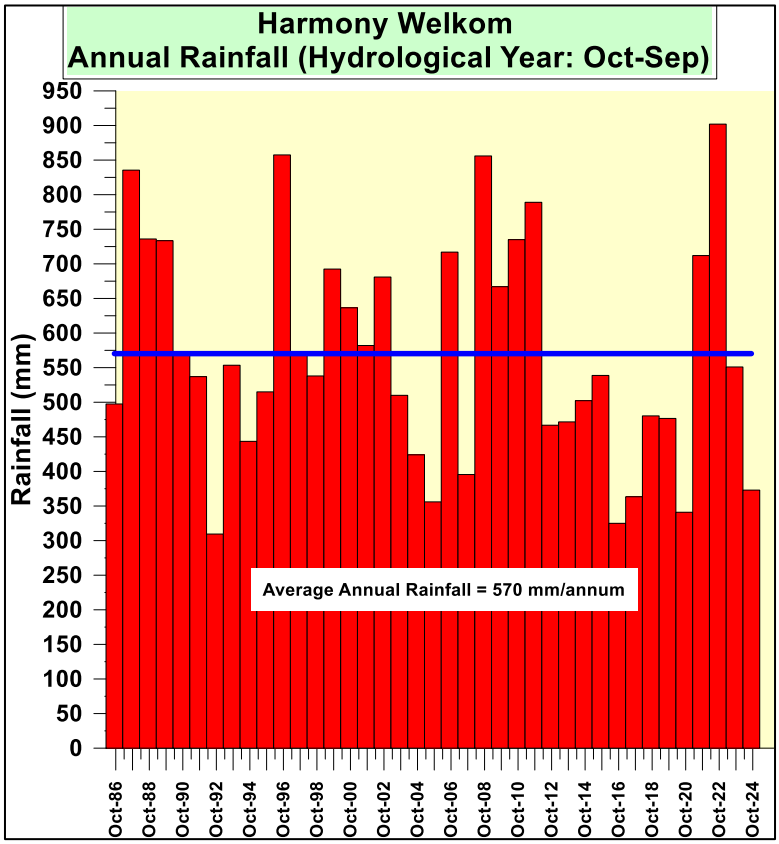


Figure 2-4 Harmony Welkom Annual Rainfall Record.

Table 2-2 Temperature Statistics for the Welkom Area.

Item	January (°C)	June (°C)
Maximum	34.0	21.9
Mean daily maximum	29.4	17.2
Mean daily temperature	23.0	9.7
Mean daily minimum	16.6	2.3
Minimum	12.1	-2.9

2.3.3 Evaporation

Evaporation from an open water surface, highest during the summer months, decreases quite markedly during winter. Warmer and windy conditions during August and September result in a rapid increase in evaporation. According to the Water Resources Management of South Africa (DWAF, 1986) the evaporation rate from an open water source is 1600-1800 mm/annum for the Welkom Area. Evaporation therefore exceeds the rainfall in the area by a factor of three indicating the level of water deficiency in the area.

2.4 Topography and Drainage

The drainage features of the study area and topography contours are depicted in Figure 2-5 and Figure 2-6 respectively. The study area consists of various sub-catchments and the surface drainage direction across the study area is mainly from the southeast towards the northwest. The study area is drained by six drainage features namely the:

- Sand River.
- Sand Spruit.
- Mahem Spruit.
- Doring River.
- Merrie Spruit.
- Riet Spruit.

A further characteristic of the study area is the various inland drainage pans which can be observed from the topography map (Figure 2-6). The most notable pans in the area are:

- Dankbaar Pan and Brak Pan in the west of the study area to the north of the Mahem Spruit.
- Flamingo Pan and Toronto Pan immediately to the west of Welkom.
- Wit Pan to the southeast of Welkom.
- Doring Pan further to the east of Welkom.

2.4.1 The Sand River

The Sand River forms the main and largest drainage feature in the study area. The Sand River is the only drainage feature which does not originate from within the study area. The origin of the Sand River is some 120 kilometres southeast from the study area in the Senekal District. The Sand River eventually discharges its water flow into the Bloemhof Dam which is situated some 120 kilometres to the northwest of the study area. Most of the surface water run-off generated across the Harmony Welkom Lease Areas drain into the Sand River.

2.4.2 The Sand Spruit

The Sand Spruit originates within the study area in the vicinity of the Koppie Alleen area and drains the northeastern portion of the study area. The Sand Spruit drains from the southeast towards the northwest and receive surface run-off from mainly the Target, Phakisa and Tshepong Operations.

2.4.3 The Mahem Spruit

The Mahem Spruit originates within the study area from the Rheeders Dam which is situated to the northwest of Welkom and drains the centre/western portions of the study area. The Mahem Spruit drains from east to west.

2.4.4 The Doring River

The Doring River originates within the study area to the south from the Joel Operation and drains from southeast to northwest. It flows into the Sand River approximately 19 kilometres to the northwest of the Joel Operation.

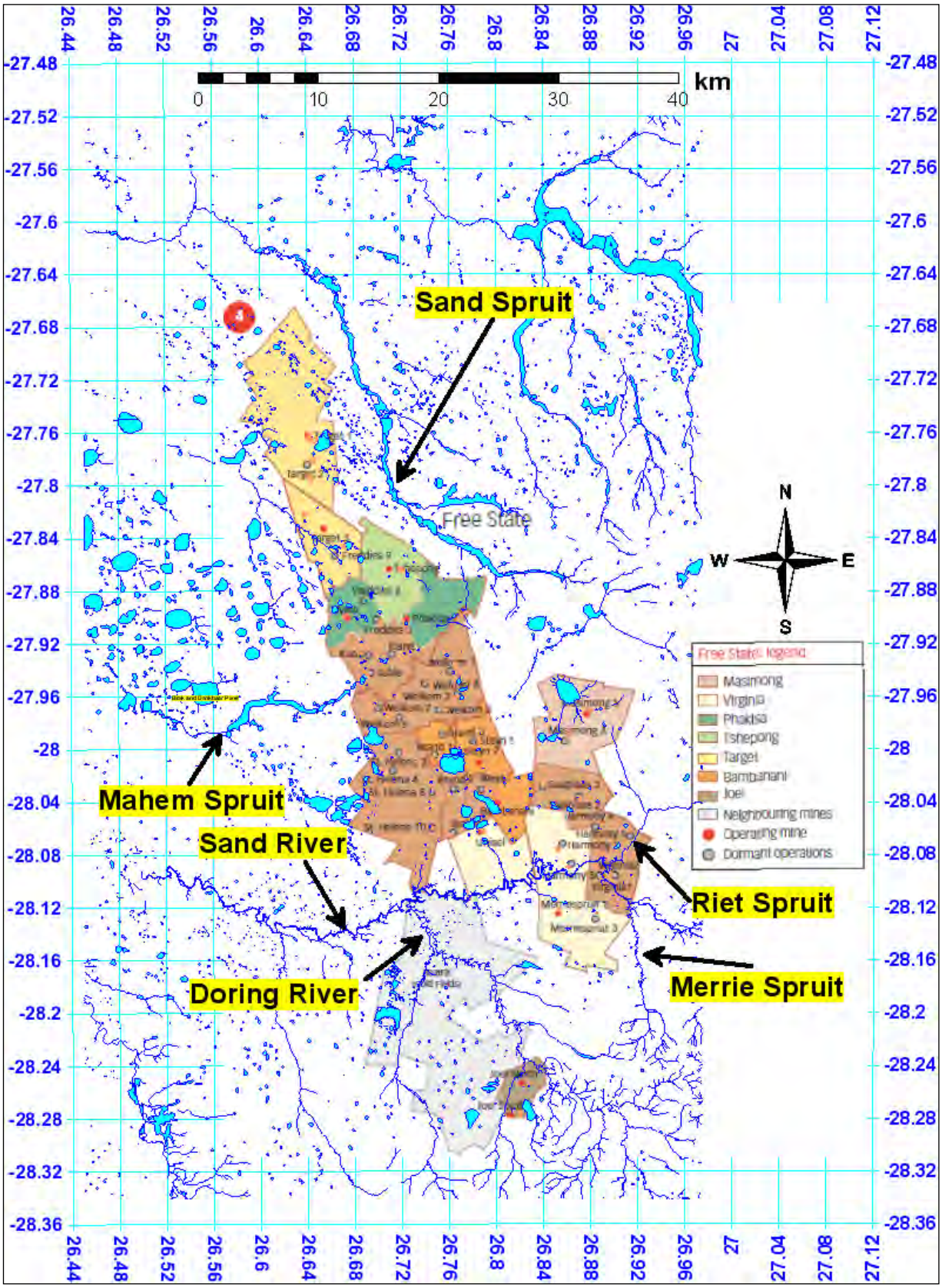


Figure 2-5 Drainage Features across the Study Area.

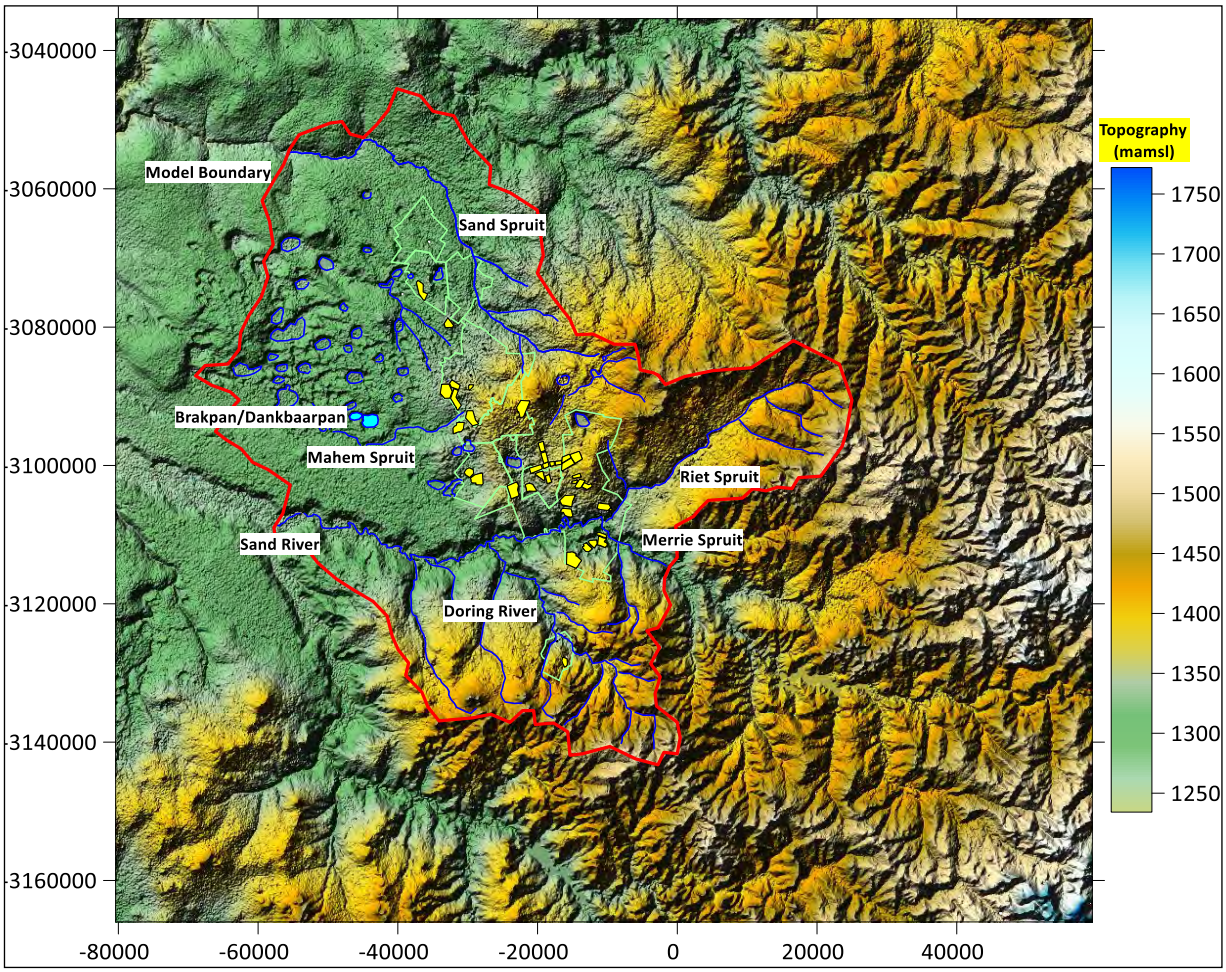


Figure 2-6 Topography Relief across the Study Area (Lease Areas in Green; Slimes Dams in Yellow).

2.4.5 The Merrie Spruit

The Merrie Spruit originates within the study area approximately 10 kilometres to the east-northeast from the Joel Operation and drains from south to north where it discharges into the Sand River.

2.4.6 The Riet Spruit

The Riet Spruit originates within the study area and drains the study area to the north of the Sand River in the Virginia area. It drains from the northeast towards the southwest and also discharges into the Sand River.

2.4.7 Ultimate Receptors for the different Sub-Catchments of the Study Area.

The receptors for the different sub-catchments selected for the study area are as follow in order of proximity and sequence:

- Sand River.
- Bloemhof Dam.
- Vaal River.
- Orange River.

- Atlantic Ocean.

2.4.8 Surface Relief

The surface relief for the study area, depicted in Figure 2-6, were determined from data sourced from 90m-grid topographical data obtained from the USGS Shuttle Radar Topography Mission (SRTM), which was a joint venture between NASA and the NGA (National Geospatial-Intelligence Agency). The data covers a 90m grid configuration and was contoured using the Kriging algorithm of the SURFER software package (Golden Software, 2008). This data set has been correlated with the 1:50 000-topocadastral map's contour values and accuracy and resolutions are as good or exceeding that of the topocadastral map. The area is characterized by small elevation contrasts (flat and undulating) and the largest observed surface gradients are in the Doring River catchment (Joel Mine) where gradients of less than 1% are calculated. Elevations across the study area vary between 1580 mamsl and 1260 mamsl.

3 Geology of the Study Area

3.1 Relevance of the Geology

The geology of an area under investigation is normally closely linked to the geohydrology and it is therefore important to be considered during a groundwater investigation.

3.2 Sequential Geology

The surface geology of the area predominantly consists of the Karoo Sequence. In depth, the Karoo Sequence is underlain by the Ventersdorp Supergroup and the Witwatersrand Supergroup. The Basal Reef, Leader Reef, B Reef, A Reef, Beatrix Reef and Elsburg Reefs are included in the Witwatersrand Supergroup. For purposes of this study, only the near surface geology is considered.

3.3 Regional Surface Geology

The expression of the surface geology of the study area was obtained from the 1:250 000 scale published map (2826 Winburg and 2726 Kroonstad). The extracted surface geology associated with the selected modelling domain is depicted in Figure 3-1. The geology of the area includes, in chronological order (oldest first):

- Witwatersrand Supergroup.
- Ventersdorp Supergroup; and
- Karoo Sequence.

3.3.1 Witwatersrand Supergroup

The Witwatersrand Basin is a thick sequence of shale, quartzite and conglomerate.

3.3.2 Ventersdorp Supergroup

The younger Ventersdorp Supergroup overlies the Witwatersrand rocks. Although acid lavas and sedimentary intercalations occur, the Ventersdorp is composed largely of andesitic lavas and related pyroclastics. The Ventersdorp Supergroup consists of the Platberg Group and the Klipriviersberg Group.

3.3.3 Karoo Sequence

The Karoo Sequence was deposited approximately 345 million years ago. It commenced with glacial period during which most of South Africa was covered by a thick sheet of ice. This ice cap slowly moved towards the south, causing extensive erosion of the underlying rocks. The erosion debris was eventually deposited as the Dwyka tillite. The latter is only partially preserved in the study area, as are the younger sedimentary deposits of the Karoo Sequence comprising mudstone, shale and sandstone.

Rocks of the Ecca Group of the Karoo Super Group cover the whole area. The formation consists mainly of dark coloured shales and mudstones with intercalations of fine- to coarse-grained sandstones. These Karoo sediments dip gently to the east and are intruded by dykes and sheets of Karoo dolerite and are covered extensively by soil and sand.

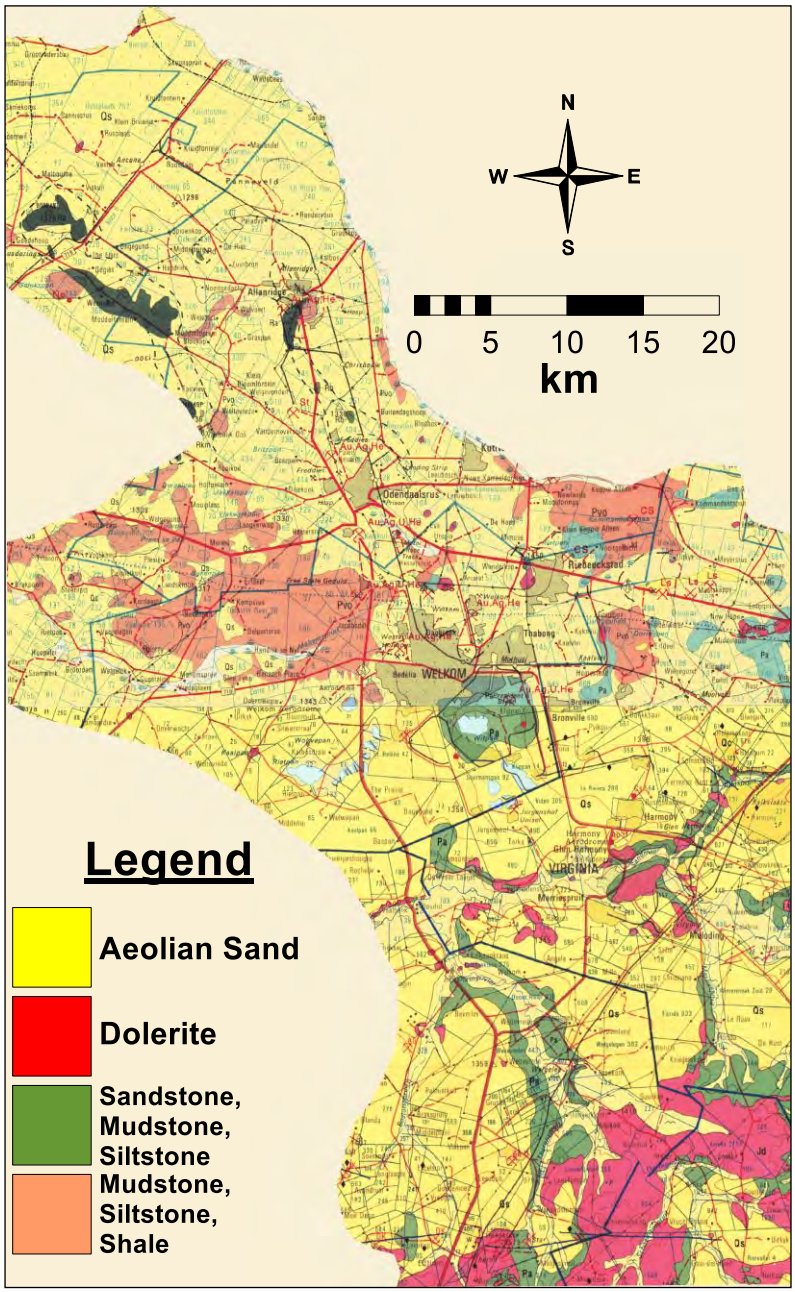


Figure 3-1 Surface Geology of the Study Area.

Most of the Karoo sediments are saturated. However, primary aquifers only exist within sandstone horizons and sandstone lenses in the younger Beaufort Group and are directly recharged from precipitation. The shale and mudstones of the Ecca Group generally function as aquicludes. Aquifers in the Ecca Group only occur in the weathered zone of the sediments directly beneath the surface, in fractured zones and at the contact between dykes and country rock.

3.4 Structural Geology

The development and preservation of the Witwatersrand Basin is structurally controlled. The structural patterns control the regional flow of groundwater. It is important to understand which structural features act as conduits, and which act as groundwater flow barriers. Dykes and sills of at least four different ages have intruded the Witwatersrand strata. The intrusion of the dykes has often taken place along fault planes. The oldest dykes are usually diabase, representing feeder dykes to

the overlying Ventersdorp lavas. There are intrusions of pyroxenite, gabbro and dolerite probably of Bushveld age. A third group belongs to the basic or alkaline dyke swarm related to the Pilansberg alkaline complex. Finally, the youngest intrusions are of Karoo dolerite.

4 Hydrogeology of the Study Area

4.1 Available Information

Section 1.5 depicts the various sources of information from which the hydrogeological conceptual model can be developed. The remainder of this section of the report aims to synthesize the information sourced from the various sources.

4.2 Monitoring Borehole Positions

The borehole positions of the three hundred and eleven (311) monitoring boreholes across the study area are depicted in Figure 4-1 to Figure 4-8. Because of the size of the study area, it is not possible to depict all the monitoring boreholes onto a single map. These boreholes are spatially distributed around the tailings facilities to monitor groundwater conditions associated with the possible impacts emanating from these TSF complexes.

Information available at these boreholes are water levels and water quality measured at various time intervals. No drilling information depicting the geology encountered or any other hydrogeological testing data are available at these sites. Table 4-1 shows the borehole coordinates and the surface elevations for the 311 monitoring boreholes. Table 4-2 shows the monitoring boreholes where water level monitoring records could be obtained – the most recent water level available for that location is reported.

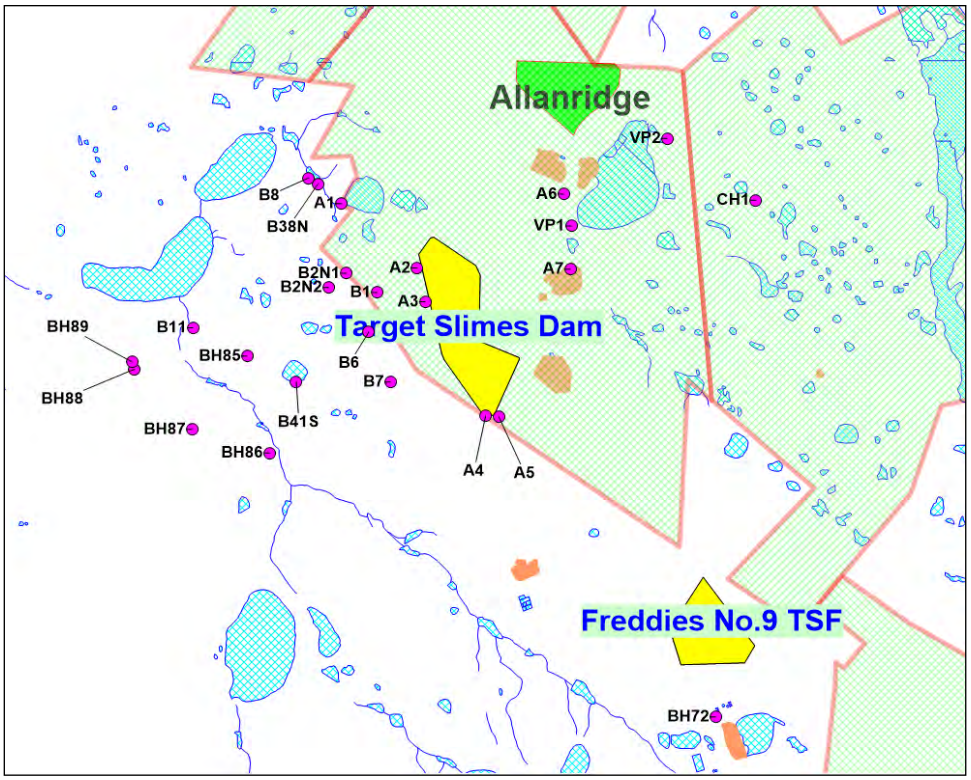


Figure 4-1 Monitoring boreholes near the Target Slimes Dam and the Freddies No. 9 TSF.

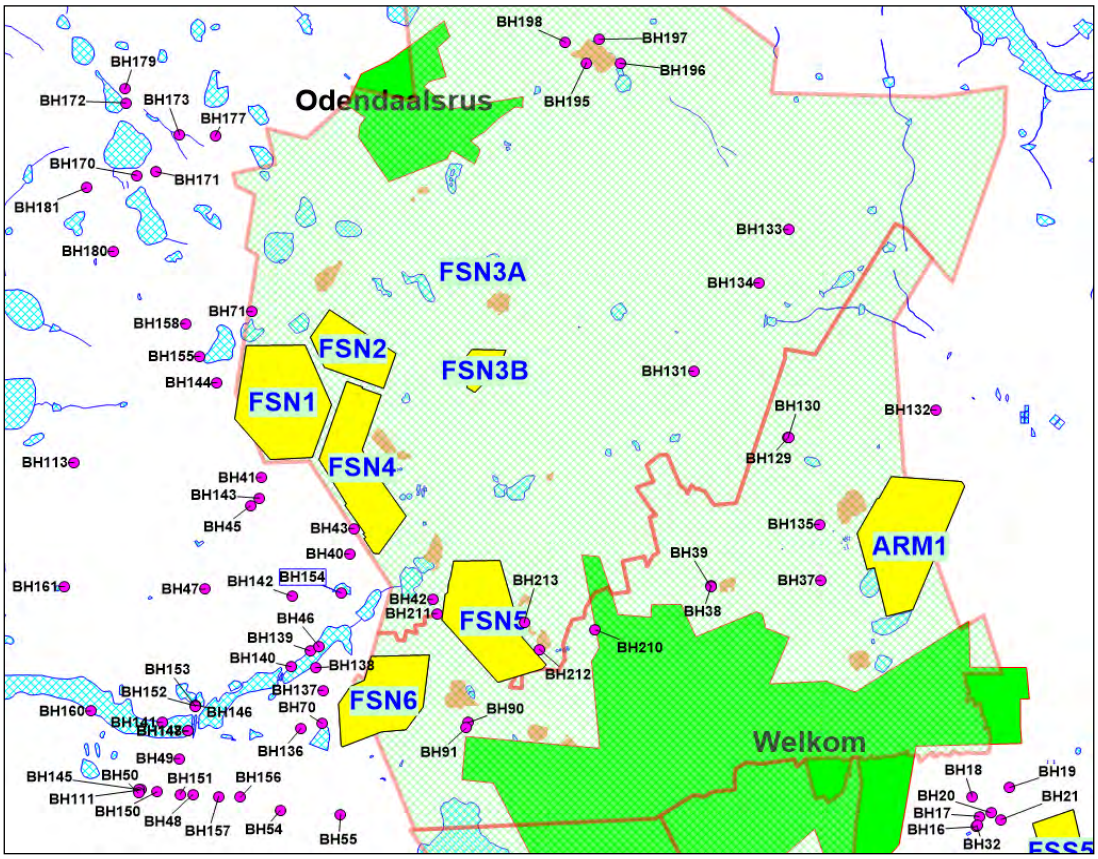


Figure 4-2 Monitoring boreholes near the Free State Geduld (Freddies) Mine Slimes Dams.

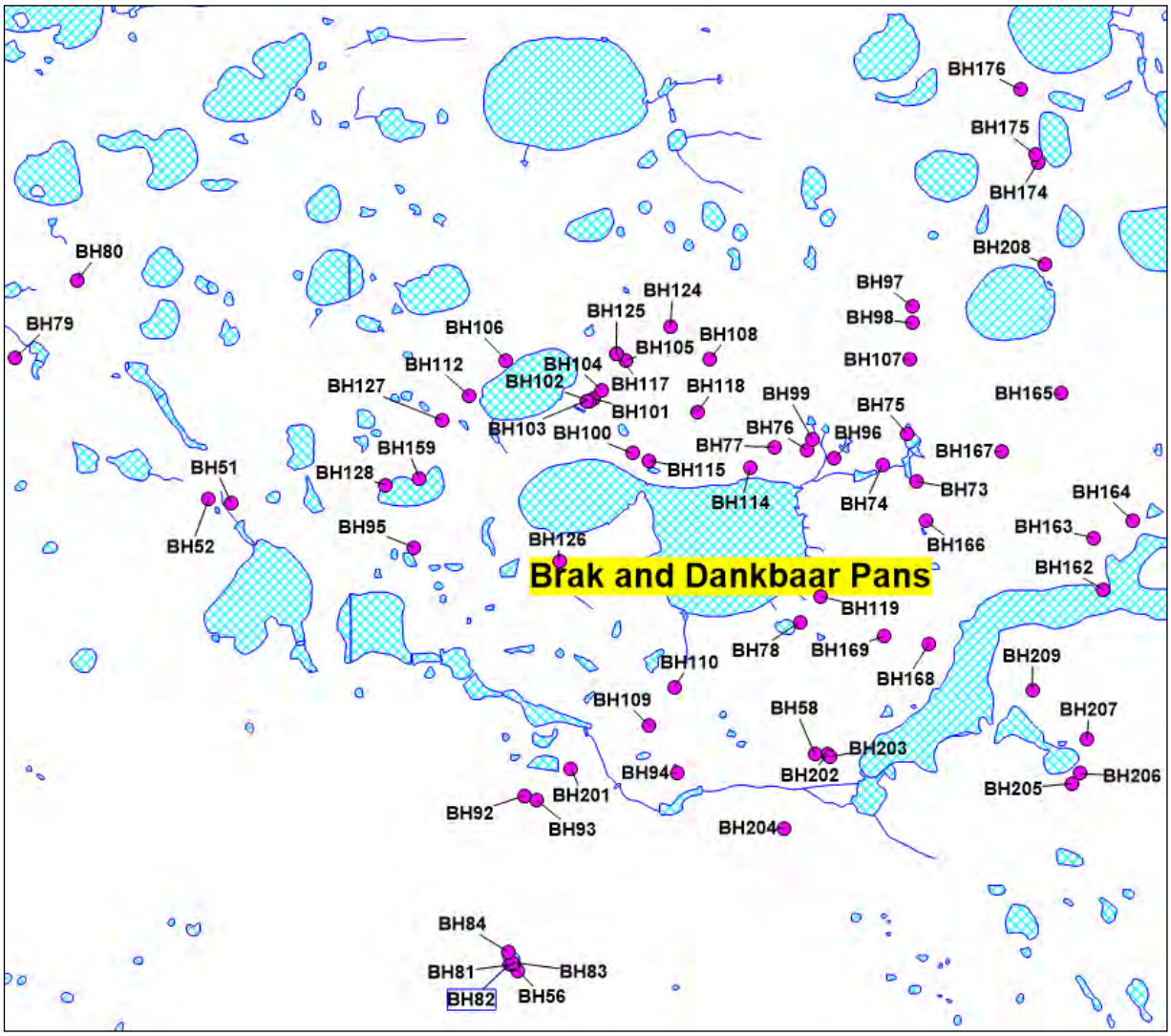


Figure 4-3 Monitoring boreholes near the Brak and Dankbaar Pans, and Mahem Spruit and downstream of the Free State Geduld (Freddies) Mine.

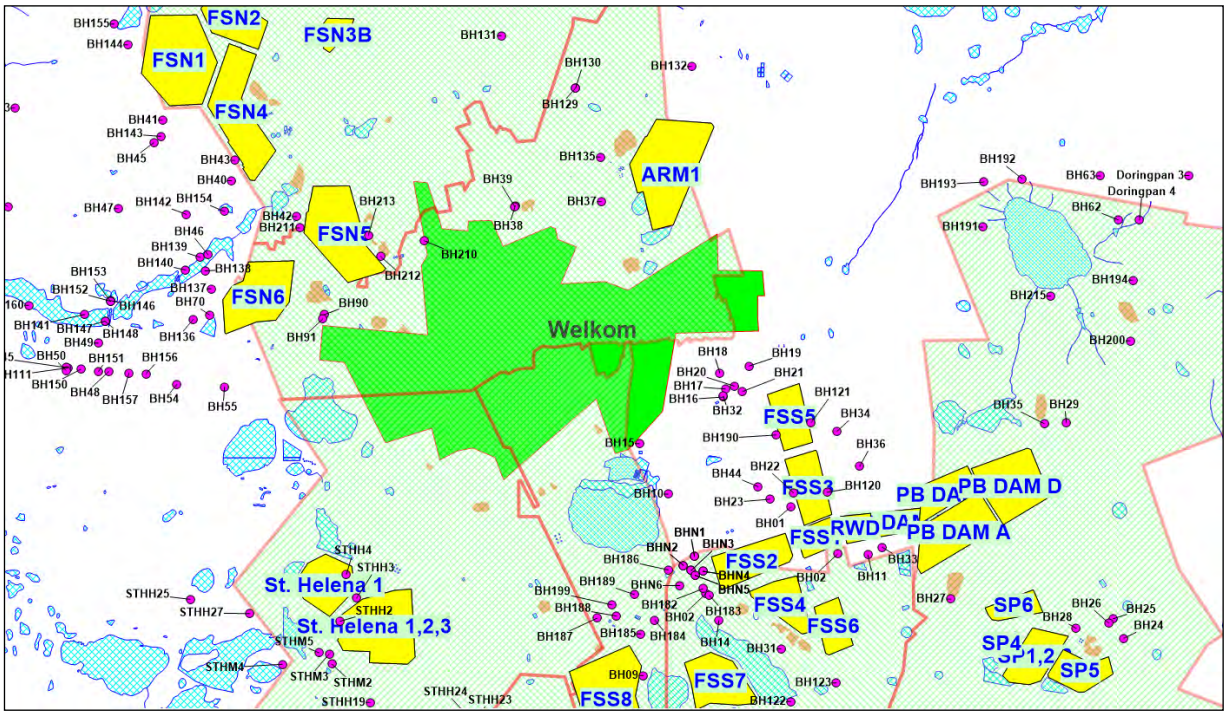


Figure 4-4 Monitoring boreholes near the ARM Slimes Dam (north-northeast of Welkom) and Slimes Dams of the Pres Steyn Gold Mine (southeast of Welkom).

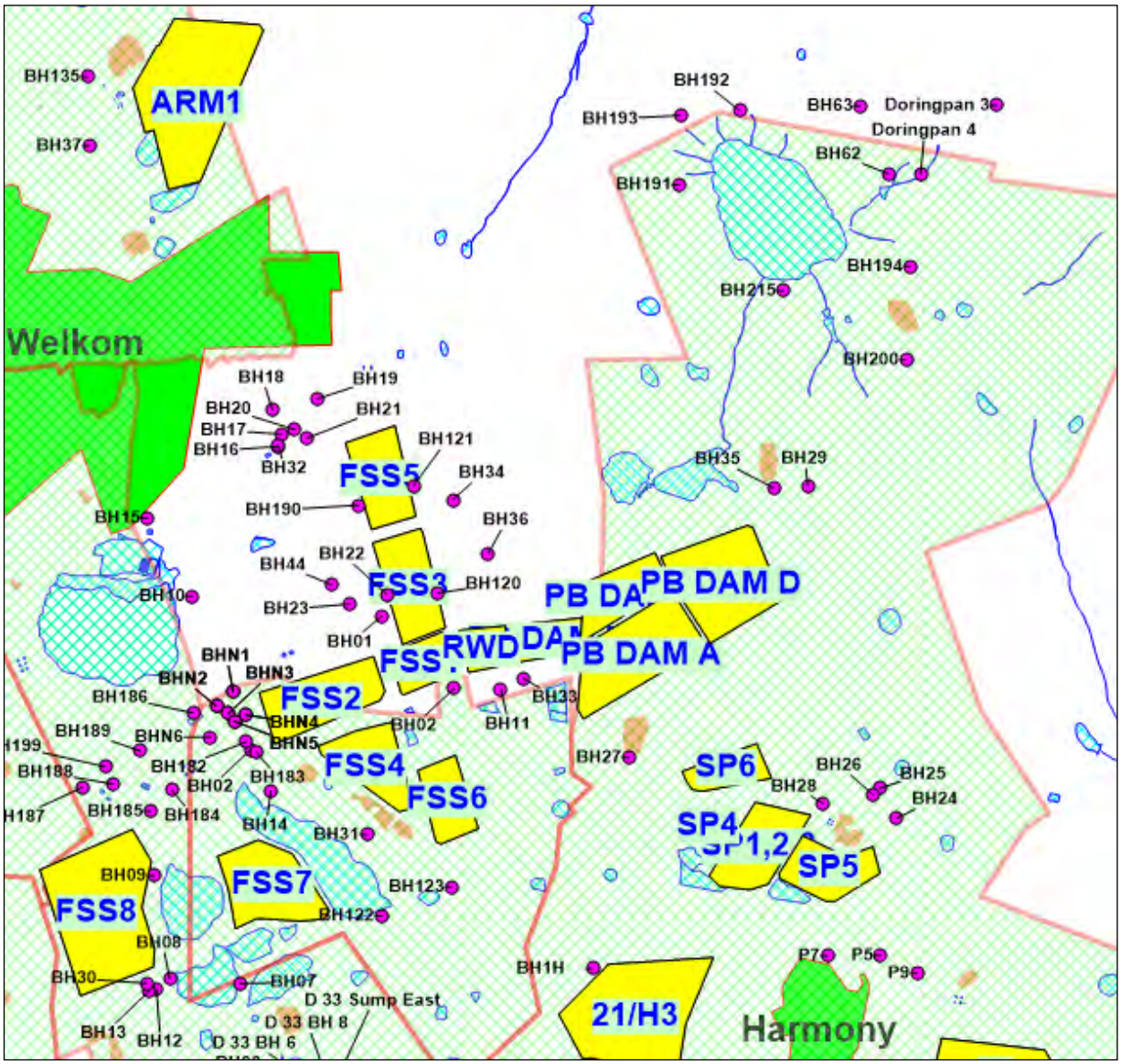


Figure 4-5 Monitoring boreholes near the Pres Steyn Gold Mine Slimes Dams (southeast of Welkom) and near the Wit Pan and Doring Pan.

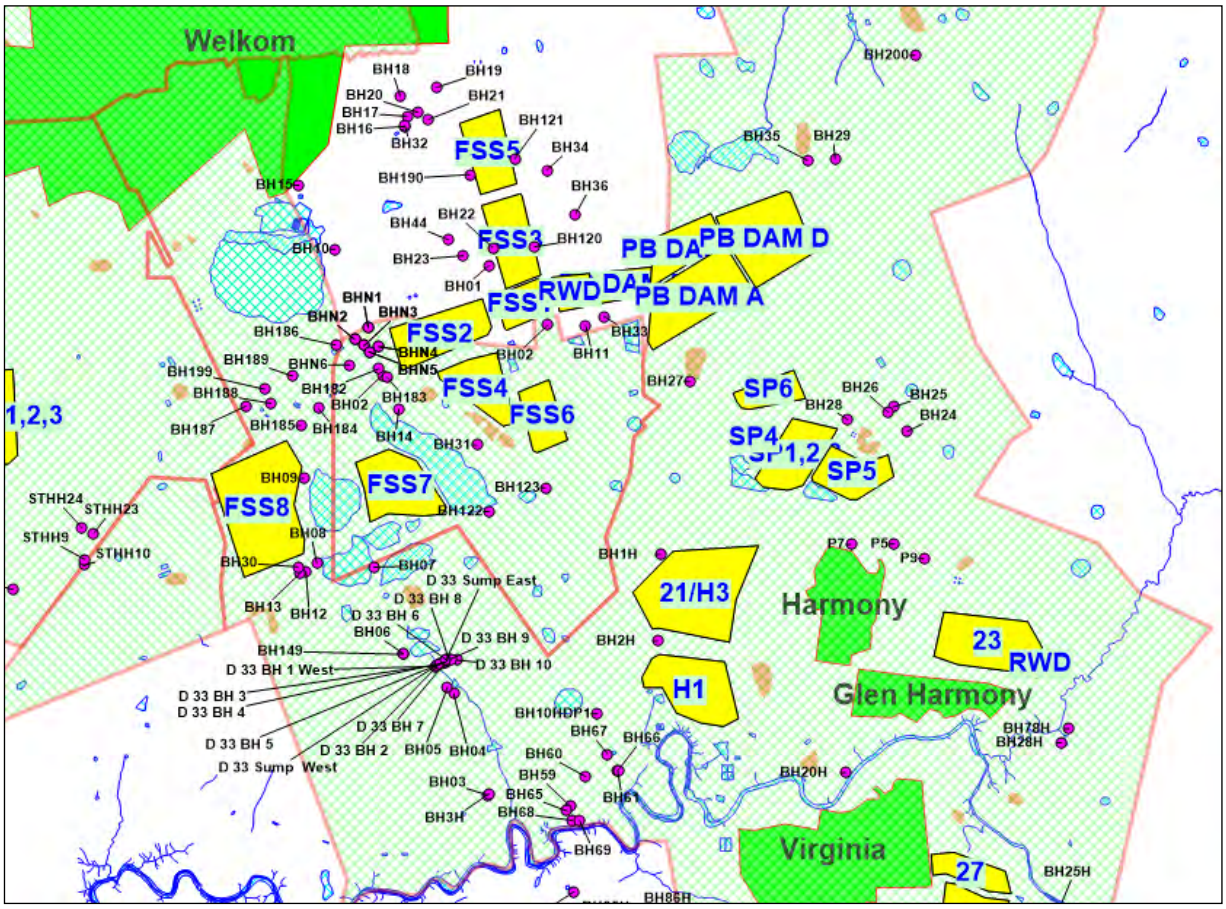


Figure 4-6 Monitoring boreholes near the Pres Brand Gold Mine Slimes Dams and Harmony Mine Slimes Dams.

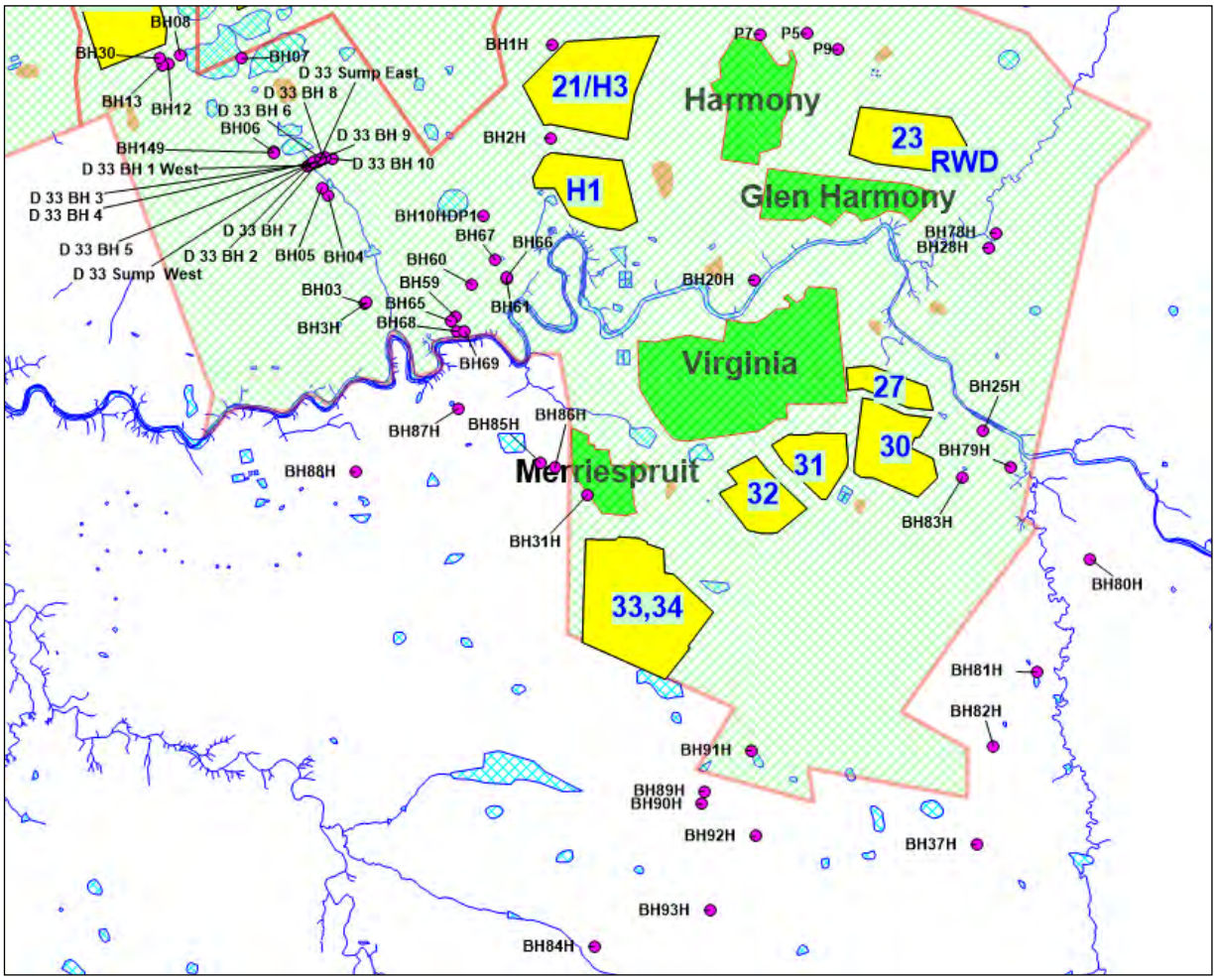


Figure 4-7 Monitoring boreholes in the area between Harmony Mine and the Sand River.

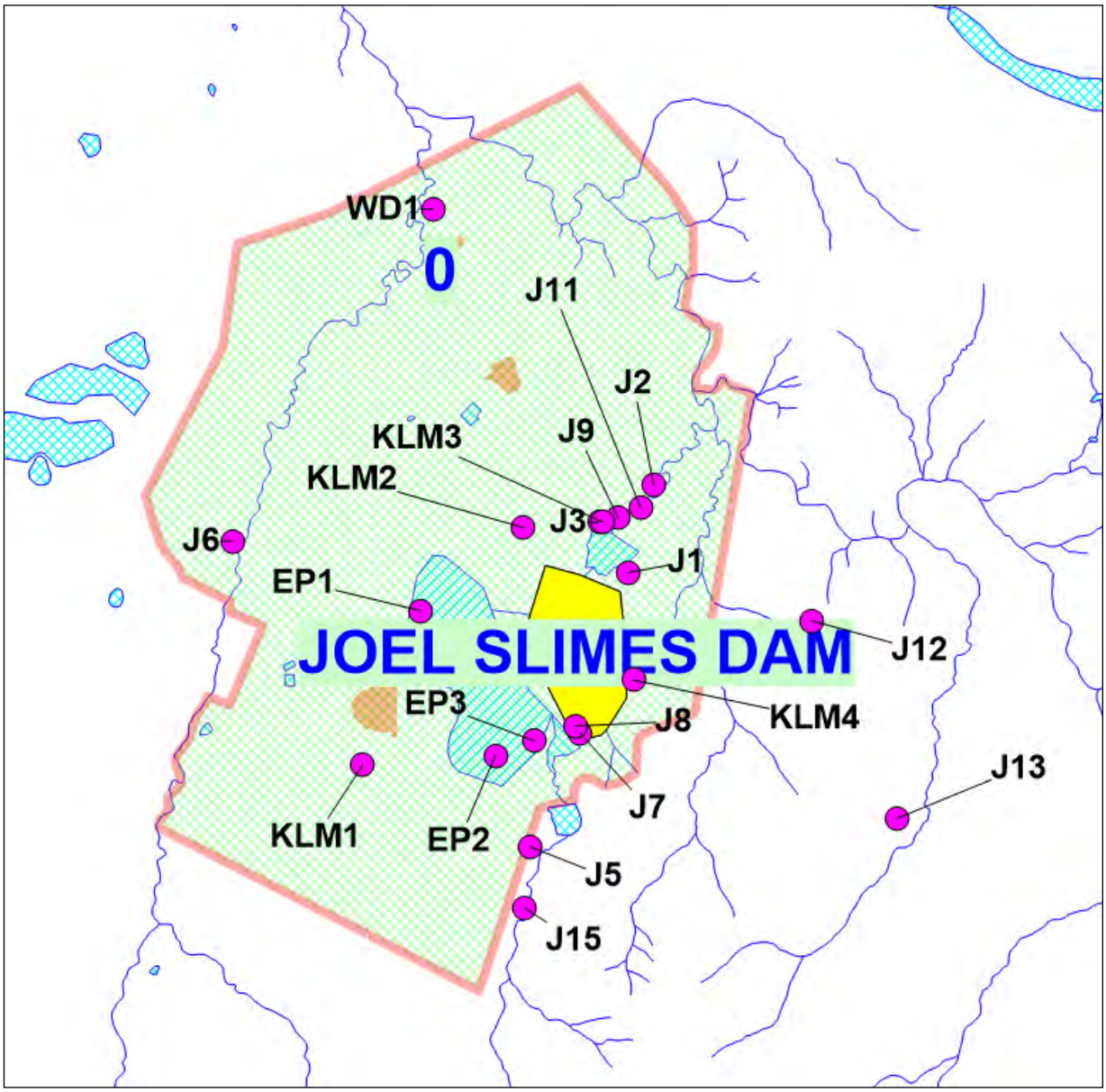


Figure 4-8 Monitoring boreholes at Joel Mine.

Table 4-1 Harmony Welkom Monitoring Borehole Coordinates.

X Co-ordinate (m) Cape LO27	Y Co-ordinate (m) Cape LO27	Borehole Identification Number	Z – Elevation (mamsl)
-38560.33	-3072741.80	A1	1305.08
-37368.08	-3073766.73	A2	1313.60
-37237.69	-3074302.57	A3	1314.83
-36281.82	-3076113.19	A4	1315.54
-36074.75	-3076120.71	A5	1314.87
-35046.86	-3072594.65	A6	1316.88
-34941.65	-3073783.90	A7	1318.79
-37993.00	-3074156.00	B1	1308.79
-40909.51	-3074713.27	B11	1300.92
-38482.81	-3073850.14	B2N1	1307.43
-38763.89	-3074074.85	B2N2	1306.72

X Co-ordinate (m) Cape LO27	Y Co-ordinate (m) Cape LO27	Borehole Identification Number	Z – Elevation (mamsl)
-38932.39	-3072432.45	B38N	1304.01
-39274.93	-3075570.66	B41S	1300.25
-38129.00	-3074784.00	B6	1307.40
-37785.83	-3075574.19	B7	1307.61
-39085.54	-3072338.23	B8	1303.85
-19397.90	-3099291.73	BH01	1353.27
-18347.31	-3100340.58	BH02	1357.99
-19417.94	-3108679.39	BH03	1311.67
-20027.78	-3106881.90	BH04	1326.29
-20135.05	-3106764.04	BH05	1327.41
-20925.09	-3106170.41	BH06	1335.76
-21449.98	-3104634.85	BH07	1337.78
-22466.03	-3104568.23	BH08	1342.41
-22695.31	-3103065.54	BH09	1343.57
-22134.57	-3099000.71	BH10	1347.53
-45265.86	-3092265.74	BH100	1303.82
-45804.31	-3091508.66	BH101	1298.62
-45867.46	-3091539.37	BH102	1299.17
-45905.88	-3091539.29	BH103	1299.55
-45693.76	-3091393.75	BH104	1299.79
-45357.59	-3090977.81	BH105	1303.22
-47017.97	-3090982.24	BH106	1295.12
-41431.83	-3090974.44	BH107	1316.22
-44197.18	-3090962.91	BH108	1309.98
-45031.75	-3096017.70	BH109	1304.66
-17472.07	-3107235.83	BH10HDP1	1327.42
-17672.32	-3100355.04	BH11	1361.61
-44680.33	-3095482.51	BH110	1304.57
-35555.83	-3096167.28	BH111	1323.30
-47524.05	-3091473.05	BH112	1297.15
-36740.29	-3090347.48	BH113	1327.61
-43639.81	-3092461.06	BH114	1297.64
-45034.21	-3092364.14	BH115	1299.29
-45491.60	-3090884.59	BH117	1303.34
-44374.07	-3091693.51	BH118	1305.89
-42668.02	-3094234.28	BH119	1302.06
-22658.80	-3104715.48	BH12	1346.45
-18580.34	-3098955.11	BH120	1355.31
-18939.00	-3097395.57	BH121	1360.49
-19395.67	-3103647.71	BH122	1344.32
-18379.59	-3103230.12	BH123	1350.33
-44747.34	-3090522.29	BH124	1309.24
-45491.34	-3090884.72	BH125	1303.34
-46281.48	-3093754.00	BH126	1300.11
-47902.84	-3091807.04	BH127	1302.60
-48680.47	-3092700.12	BH128	1293.90
-24211.75	-3089900.82	BH129	1376.10
-22760.13	-3104741.34	BH13	1347.62
-24207.51	-3089900.81	BH130	1376.10
-25867.12	-3088723.84	BH131	1360.17

X Co-ordinate (m) Cape LO27	Y Co-ordinate (m) Cape LO27	Borehole Identification Number	Z – Elevation (mamsl)
-21610.02	-3089413.71	BH132	1397.66
-24207.65	-3086202.21	BH133	1378.42
-24716.87	-3087153.43	BH134	1371.09
-23656.70	-3091444.92	BH135	1392.92
-32756.44	-3095077.65	BH136	1328.04
-32361.11	-3094397.41	BH137	1329.78
-32499.82	-3093996.40	BH138	1327.29
-32599.91	-3093694.23	BH139	1325.94
-21001.99	-3101832.04	BH14	1346.92
-32928.56	-3093977.07	BH140	1325.11
-35185.01	-3094971.40	BH141	1315.74
-32916.28	-3092726.36	BH142	1332.14
-33480.63	-3090980.41	BH143	1338.36
-34227.21	-3088926.93	BH144	1337.01
-35597.97	-3096163.30	BH145	1323.46
-34605.15	-3094661.55	BH146	1320.91
-34734.73	-3095123.58	BH147	1318.54
-34734.72	-3095123.94	BH148	1318.55
-20924.31	-3106182.42	BH149	1335.56
-22783.34	-3097867.13	BH15	1352.12
-35276.82	-3096202.34	BH150	1324.05
-34880.91	-3096248.74	BH151	1326.06
-34610.23	-3094675.54	BH152	1320.91
-34608.71	-3094683.13	BH153	1320.81
-32057.92	-3092666.09	BH154	1331.23
-34526.08	-3088460.57	BH155	1336.56
-33818.40	-3096302.70	BH156	1332.46
-34199.30	-3096286.71	BH157	1330.20
-34783.17	-3087876.43	BH158	1335.60
-48217.97	-3092603.54	BH159	1292.37
-20905.83	-3096823.94	BH16	1363.02
-36440.12	-3094769.96	BH160	1313.48
-36909.03	-3092555.61	BH161	1319.18
-38753.79	-3094138.34	BH162	1307.62
-38885.04	-3093427.14	BH163	1316.14
-38347.71	-3093192.80	BH164	1315.67
-39347.19	-3091439.40	BH165	1323.24
-41217.51	-3093190.43	BH166	1312.53
-40165.73	-3092235.58	BH167	1320.69
-41166.65	-3094890.27	BH168	1307.58
-41794.38	-3094789.52	BH169	1307.63
-20854.74	-3096642.33	BH17	1363.79
-35637.03	-3085238.40	BH170	1331.45
-35303.36	-3085174.23	BH171	1330.03
-35831.99	-3083948.99	BH172	1326.93
-34887.79	-3084513.88	BH173	1331.64
-39662.17	-3088261.81	BH174	1321.41
-39696.58	-3088150.40	BH175	1321.95
-39903.01	-3087247.31	BH176	1321.43
-34262.19	-3084546.53	BH177	1332.29

X Co-ordinate (m) Cape LO27	Y Co-ordinate (m) Cape LO27	Borehole Identification Number	Z – Elevation (mamsl)
-35842.09	-3083704.33	BH179	1328.99
-20981.14	-3096286.51	BH18	1365.99
-36043.04	-3086590.14	BH180	1329.86
-36521.80	-3085459.49	BH181	1331.05
-21354.00	-3101119.00	BH182	1345.98
-21215.00	-3101268.00	BH183	1346.69
-22435.00	-3101823.00	BH184	1346.89
-22746.00	-3102132.00	BH185	1346.09
-22130.07	-3100698.38	BH186	1354.29
-23728.00	-3101780.00	BH187	1350.77
-23289.73	-3101731.56	BH188	1348.33
-22894.02	-3101249.34	BH189	1348.75
-20323.99	-3096127.84	BH19	1369.09
-19725.04	-3097674.53	BH190	1361.88
-15092.82	-3093012.44	BH191	1375.24
-14218.60	-3091932.74	BH192	1381.45
-15074.40	-3092003.75	BH193	1379.46
-11744.83	-3094202.80	BH194	1382.70
-27749.15	-3083239.11	BH195	1349.30
-27158.03	-3083243.30	BH196	1345.16
-27524.85	-3082817.94	BH197	1341.21
-28117.13	-3082865.47	BH198	1343.69
-23394.03	-3101481.98	BH199	1350.95
-16342.51	-3104413.47	BH1H	1350.08
-20654.21	-3096577.25	BH20	1363.24
-11803.92	-3095564.29	BH200	1387.36
-46115.58	-3096604.28	BH201	1300.47
-42568.64	-3096403.25	BH202	1303.09
-42539.25	-3096442.92	BH203	1302.58
-43168.47	-3097426.85	BH204	1303.56
-39196.56	-3096813.70	BH205	1308.92
-39083.56	-3096676.40	BH206	1308.73
-38988.46	-3096205.31	BH207	1309.02
-39557.01	-3089651.53	BH208	1317.90
-39740.74	-3095523.25	BH209	1306.45
-13033.52	-3108283.16	BH20H	1305.24
-20473.35	-3096698.11	BH21	1361.80
-27591.33	-3093323.55	BH210	1374.62
-30368.47	-3093035.17	BH211	1340.25
-28574.04	-3093670.60	BH212	1362.81
-28841.72	-3093194.03	BH213	1356.07
-13576.60	-3094559.10	BH215	1365.51
-19328.00	-3098971.73	BH22	1358.39
-19857.49	-3099114.19	BH23	1355.91
-11941.51	-3102231.24	BH24	1383.67
-12187.50	-3101793.20	BH25	1389.43
-9267.98	-3110772.90	BH25H	1313.51
-12283.15	-3101889.15	BH26	1387.71
-15815.92	-3101350.37	BH27	1370.42
-13010.11	-3102010.40	BH28	1382.44

X Co-ordinate (m) Cape LO27	Y Co-ordinate (m) Cape LO27	Borehole Identification Number	Z – Elevation (mamsl)
-9189.44	-3107750.97	BH28H	1321.38
-13232.48	-3097391.12	BH29	1388.73
-16383.81	-3105943.66	BH2H	1334.59
-22799.24	-3104631.11	BH30	1347.03
-19613.19	-3102470.31	BH31	1349.38
-15771.39	-3111816.59	BH31H	1331.44
-20898.97	-3096804.37	BH32	1363.37
-17348.24	-3100192.80	BH33	1364.29
-18369.36	-3097599.06	BH34	1358.44
-13723.14	-3097422.67	BH35	1383.30
-17853.13	-3098375.87	BH36	1359.47
-23628.94	-3092446.56	BH37	1386.71
-9379.93	-3117578.25	BH37H	1385.60
-25556.48	-3092531.12	BH38	1384.31
-25569.45	-3092551.84	BH39	1384.09
-19397.64	-3108654.81	BH3H	1310.91
-31904.27	-3091973.03	BH40	1333.61
-33442.29	-3090619.50	BH41	1338.13
-30444.79	-3092781.88	BH42	1337.84
-31827.65	-3091518.78	BH43	1336.39
-20127.75	-3098828.36	BH44	1354.54
-33645.18	-3091118.50	BH45	1336.07
-32432.29	-3093627.78	BH46	1327.18
-34436.68	-3092600.56	BH47	1329.91
-34649.06	-3096249.44	BH48	1328.76
-34885.71	-3095613.68	BH49	1323.39
-35609.07	-3096228.28	BH50	1322.97
-50816.41	-3092949.82	BH51	1296.92
-51129.20	-3092896.43	BH52	1295.84
-33122.83	-3096537.25	BH54	1335.40
-32061.12	-3096603.98	BH55	1337.22
-46848.02	-3099391.71	BH56	1303.90
-42742.29	-3096414.33	BH58	1303.13
-17944.18	-3108876.89	BH59	1315.26
-17678.67	-3108347.22	BH60	1321.40
-17101.75	-3108248.29	BH61	1313.47
-12063.00	-3092854.10	BH62	1382.35
-12465.18	-3091866.88	BH63	1391.42
-18008.82	-3108959.15	BH65	1312.62
-17094.60	-3108234.53	BH66	1313.24
-17285.85	-3107948.31	BH67	1317.56
-17913.00	-3109126.06	BH68	1300.50
-17782.13	-3109128.64	BH69	1299.08
-32389.06	-3094985.26	BH70	1330.40
-33611.63	-3087659.75	BH71	1340.35
-32641.36	-3080887.13	BH72	1324.89
-41344.55	-3092653.31	BH73	1312.84
-41814.24	-3092422.29	BH74	1307.85
-41471.33	-3091989.43	BH75	1313.93
-42855.17	-3092211.33	BH76	1304.72

X Co-ordinate (m) Cape LO27	Y Co-ordinate (m) Cape LO27	Borehole Identification Number	Z – Elevation (mamsl)
-43306.87	-3092176.22	BH77	1305.15
-42955.37	-3094589.14	BH78	1301.32
-9059.65	-3107504.60	BH78H	1320.05
-53803.80	-3090949.15	BH79	1290.30
-8811.27	-3111354.53	BH79H	1312.95
-52952.54	-3089878.99	BH80	1293.36
-7514.39	-3112870.99	BH80H	1323.85
-46906.95	-3099304.85	BH81	1304.35
-8383.79	-3114737.65	BH81H	1336.86
-46971.25	-3099306.22	BH82	1304.69
-9103.79	-3115953.31	BH82H	1359.86
-46929.81	-3099277.60	BH83	1304.26
-9608.56	-3111529.73	BH83H	1314.77
-46981.23	-3099140.92	BH84	1302.47
-15658.65	-3119258.10	BH84H	1362.96
-40051.32	-3075163.99	BH85	1305.98
-16544.22	-3111286.41	BH85H	1334.84
-39698.85	-3076700.06	BH86	1301.73
-16301.57	-3111371.43	BH86H	1334.67
-40922.79	-3076326.86	BH87	1307.52
-17883.12	-3110392.20	BH87H	1319.70
-41839.95	-3075371.06	BH88	1303.43
-19578.04	-3111445.91	BH88H	1318.21
-41873.51	-3075257.59	BH89	1302.96
-13842.78	-3116697.48	BH89H	1376.39
-29821.59	-3094972.36	BH90	1348.66
-13887.54	-3116911.32	BH90H	1378.48
-29859.40	-3095069.93	BH91	1351.40
-13074.28	-3116029.65	BH91H	1371.56
-46763.26	-3096982.36	BH92	1301.66
-13008.17	-3117435.20	BH92H	1385.19
-46597.03	-3097039.35	BH93	1301.02
-13760.13	-3118665.88	BH93H	1382.80
-44653.18	-3096671.51	BH94	1302.57
-48287.28	-3093560.33	BH95	1300.20
-42477.80	-3092336.01	BH96	1303.94
-41389.74	-3090245.72	BH97	1320.18
-41395.61	-3090469.88	BH98	1319.43
-42780.99	-3092063.82	BH99	1304.85
-21548.64	-3100392.89	BHN1	1354.64
-21793.84	-3100600.29	BHN2	1352.31
-21620.71	-3100708.66	BHN3	1349.99
-21358.65	-3100728.43	BHN4	1349.02
-21533.11	-3100819.51	BHN5	1346.81
-21879.16	-3101048.83	BHN6	1347.72
-32003.39	-3072689.47	CH1	1318.50
-20360.23	-3106395.64	D 33 BH 1 West	1327.08
-19966.60	-3106285.63	D 33 BH 10	1329.38
-20316.90	-3106386.27	D 33 BH 2	1327.19
-20264.97	-3106361.41	D 33 BH 3	1328.01

X Co-ordinate (m) Cape LO27	Y Co-ordinate (m) Cape LO27	Borehole Identification Number	Z – Elevation (mamsl)
-20209.40	-3106330.43	D 33 BH 4	1328.41
-20176.57	-3106313.48	D 33 BH 5	1328.76
-20134.68	-3106292.95	D 33 BH 6	1329.17
-20139.37	-3106283.67	D 33 BH 7	1329.06
-20107.05	-3106277.94	D 33 BH 8	1329.48
-20081.24	-3106263.58	D 33 BH 9	1329.77
-20279.99	-3106345.06	D 33 Sump West	1327.62
-20160.32	-3106284.22	D 33 Sump East	1328.78
-10486.85	-3091858.05	Doringpan 3	1399.32
-11595.81	-3092859.46	Doringpan 4	1390.26
-17354.80	-3128094.80	EP1	1388.34
-16766.90	-3129226.00	EP2	1389.40
-16460.80	-3129112.80	EP3	1385.40
-15726.64	-3127795.87	J1	1365.13
-15634.03	-3127292.21	J11	1354.55
-14294.65	-3128175.30	J12	1374.55
-13634.88	-3129716.79	J13	1389.97
-16541.18	-3130415.64	J15	1397.70
-15531.75	-3127112.25	J2	1352.87
-15955.37	-3127404.73	J3	1360.97
-16496.39	-3129938.08	J5	1393.04
-18817.24	-3127553.47	J6	1362.97
-16105.38	-3129052.15	J7	1379.75
-16145.56	-3128995.74	J8	1378.79
-15810.97	-3127368.00	J9	1358.99
-17799.33	-3129299.22	KLM1	1406.30
-16550.51	-3127445.59	KLM2	1371.58
-15926.97	-3127403.20	KLM3	1360.68
-15690.02	-3128636.36	KLM4	1377.44
-12171.99	-3104227.65	P5	1362.04
-12942.94	-3104234.62	P7	1363.47
-11646.14	-3104489.14	P9	1361.70
-26611.00	-3104597.00	STHH10	1351.35
-27870.00	-3105033.00	STHH18	1344.49
-28804.00	-3103670.00	STHH19	1332.13
-29479.00	-3101851.00	STHH2	1330.52
-26440.00	-3104033.00	STHH23	1350.20
-26651.00	-3103940.00	STHH24	1349.18
-32829.00	-3101357.00	STHH25	1331.94
-31492.00	-3101678.00	STHH27	1324.63
-29107.00	-3101333.00	STHH3	1336.86
-29333.00	-3100795.00	STHH4	1345.64
-26602.00	-3104498.00	STHH9	1350.74
-29948.00	-3102558.00	STHM5	1326.16
-29663.00	-3102809.00	STHM2	1326.33
-29718.00	-3102578.00	STHM3	1325.82
-30768.00	-3102813.00	STHM4	1322.29
-34925.08	-3073098.41	VP1	1305.97
-33408.98	-3071710.11	VP2	1308.76
-17251.30	-3124960.30	WD1	1341.08

Table 4-2 Water levels for monitoring boreholes.

X Co-ordinate (m) Cape LO27	Y Co-ordinate (m) Cape LO27	Borehole Identification Number	Z Elevation	Water Level (mamsl)	Water Level (mbgl)
-38560.33	-3072741.80	A1	1305.08	1302.18	2.90
-37368.08	-3073766.73	A2	1313.60	1312.30	1.30
-37237.69	-3074302.57	A3	1314.83	1314.13	0.70
-36281.82	-3076113.19	A4	1315.54	1312.74	2.80
-36074.75	-3076120.71	A5	1314.87	1312.37	2.50
-38482.81	-3073850.14	B2N1	1307.43	1303.93	3.50
-38763.89	-3074074.85	B2N2	1306.72	1302.72	4.00
-38932.39	-3072432.45	B38N	1304.01	1301.91	2.10
-39274.93	-3075570.66	B41S	1300.25	1297.75	2.50
-19397.90	-3099291.73	BH01	1353.27	1350.35	2.92
-18347.31	-3100340.58	BH02	1357.99	1357.16	0.83
-19417.94	-3108679.39	BH03	1311.67	1308.57	3.10
-20027.78	-3106881.90	BH04	1326.29	1326.29	0.00
-20135.05	-3106764.04	BH05	1327.41	1324.93	2.48
-20925.09	-3106170.41	BH06	1335.76	1335.48	0.28
-22466.03	-3104568.23	BH08	1342.41	1339.58	2.83
-22134.57	-3099000.71	BH10	1347.53	1345.03	2.50
-45265.86	-3092265.74	BH100	1303.82	1293.12	10.70
-45804.31	-3091508.66	BH101	1298.62	1294.62	4.00
-45867.46	-3091539.37	BH102	1299.17	1295.97	3.20
-45905.88	-3091539.29	BH103	1299.55	1294.55	5.00
-45693.76	-3091393.75	BH104	1299.79	1295.09	4.70
-17472.07	-3107235.83	BH10HDP1	1327.42	1320.90	6.52
-17672.32	-3100355.04	BH11	1361.61	1355.41	6.20
-36740.29	-3090347.48	BH113	1327.61	1310.41	17.20
-43639.81	-3092461.06	BH114	1297.64	1290.74	6.90
-45034.21	-3092364.14	BH115	1299.29	1292.49	6.80
-45491.60	-3090884.59	BH117	1303.34	1302.24	1.10
-44374.07	-3091693.51	BH118	1305.89	1299.79	6.10
-42668.02	-3094234.28	BH119	1302.06	1293.66	8.40
-22658.80	-3104715.48	BH12	1346.45	1341.35	5.10
-18580.34	-3098955.11	BH120	1355.31	1355.21	0.10
-18939.00	-3097395.57	BH121	1360.49	1357.99	2.50
-19395.67	-3103647.71	BH122	1344.32	1341.22	3.10
-18379.59	-3103230.12	BH123	1350.33	1346.23	4.10
-44747.34	-3090522.29	BH124	1309.24	1307.74	1.50
-45491.34	-3090884.72	BH125	1303.34	1297.54	5.80
-46281.48	-3093754.00	BH126	1300.11	1297.91	2.20
-48680.47	-3092700.12	BH128	1293.90	1293.90	0.00
-24211.75	-3089900.82	BH129	1376.10	1372.35	3.75
-22760.13	-3104741.34	BH13	1347.62	1342.62	5.00
-25867.12	-3088723.84	BH131	1360.17	1354.07	6.10
-24207.65	-3086202.21	BH133	1378.42	1375.53	2.89
-24716.87	-3087153.43	BH134	1371.09	1360.94	10.15
-23656.70	-3091444.92	BH135	1392.92	1388.32	4.60
-32756.44	-3095077.65	BH136	1328.04	1295.04	33.00
-32361.11	-3094397.41	BH137	1329.78	1325.18	4.60
-32499.82	-3093996.40	BH138	1327.29	1323.10	4.19

X Co-ordinate (m) Cape LO27	Y Co-ordinate (m) Cape LO27	Borehole Identification Number	Z Elevation	Water Level (mamsl)	Water Level (mbgl)
-32599.91	-3093694.23	BH139	1325.94	1322.94	3.00
-21001.99	-3101832.04	BH14	1346.92	1345.42	1.50
-32928.56	-3093977.07	BH140	1325.11	1322.21	2.90
-35185.01	-3094971.40	BH141	1315.74	1306.35	9.39
-32916.28	-3092726.36	BH142	1332.14	1325.64	6.50
-33480.63	-3090980.41	BH143	1338.36	1331.16	7.20
-34227.21	-3088926.93	BH144	1337.01	1319.01	18.00
-35597.97	-3096163.30	BH145	1323.46	1316.46	7.00
-34605.15	-3094661.55	BH146	1320.91	1313.67	7.24
-34734.73	-3095123.58	BH147	1318.54	1317.04	1.50
-34734.72	-3095123.94	BH148	1318.55	1318.55	0.00
-22783.34	-3097867.13	BH15	1352.12	1346.02	6.10
-34610.23	-3094675.54	BH152	1320.91	1305.51	15.40
-33818.40	-3096302.70	BH156	1332.46	1325.46	7.00
-20905.83	-3096823.94	BH16	1363.02	1359.12	3.90
-38753.79	-3094138.34	BH162	1307.62	1303.67	3.95
-38885.04	-3093427.14	BH163	1316.14	1304.84	11.30
-20854.74	-3096642.33	BH17	1363.79	1361.19	2.60
-35637.03	-3085238.40	BH170	1331.45	1327.27	4.18
-39903.01	-3087247.31	BH176	1321.43	1309.45	11.98
-34262.19	-3084546.53	BH177	1332.29	1325.12	7.17
-20981.14	-3096286.51	BH18	1365.99	1363.49	2.50
-21354.00	-3101119.00	BH182	1345.98	1343.80	2.18
-21215.00	-3101268.00	BH183	1346.69	1343.89	2.80
-22435.00	-3101823.00	BH184	1346.89	1345.09	1.80
-22746.00	-3102132.00	BH185	1346.09	1344.59	1.50
-22130.07	-3100698.38	BH186	1354.29	1345.39	8.90
-23728.00	-3101780.00	BH187	1350.77	1347.67	3.10
-23289.73	-3101731.56	BH188	1348.33	1347.53	0.80
-22894.02	-3101249.34	BH189	1348.75	1346.60	2.15
-20323.99	-3096127.84	BH19	1369.09	1364.59	4.50
-19725.04	-3097674.53	BH190	1361.88	1361.38	0.50
-15074.40	-3092003.75	BH193	1379.46	1374.96	4.50
-27749.15	-3083239.11	BH195	1349.30	1344.34	4.96
-27158.03	-3083243.30	BH196	1345.16	1337.46	7.70
-27524.85	-3082817.94	BH197	1341.21	1340.21	1.00
-28117.13	-3082865.47	BH198	1343.69	1333.59	10.10
-23394.03	-3101481.98	BH199	1350.95	1348.65	2.30
-16342.51	-3104413.47	BH1H	1350.08	1348.57	1.51
-20654.21	-3096577.25	BH20	1363.24	1359.04	4.20
-39557.01	-3089651.53	BH208	1317.90	1308.10	9.80
-39740.74	-3095523.25	BH209	1306.45	1301.93	4.52
-13033.52	-3108283.16	BH20H	1305.24	1299.14	6.10
-20473.35	-3096698.11	BH21	1361.80	1356.80	5.00
-27591.33	-3093323.55	BH210	1374.62	1366.72	7.90
-30368.47	-3093035.17	BH211	1340.25	1335.05	5.20
-28574.04	-3093670.60	BH212	1362.81	1357.91	4.90
-28841.72	-3093194.03	BH213	1356.07	1353.77	2.30
-13576.60	-3094559.10	BH215	1365.51	1351.21	14.30
-19328.00	-3098971.73	BH22	1358.39	1359.59	-1.20

X Co-ordinate (m) Cape LO27	Y Co-ordinate (m) Cape LO27	Borehole Identification Number	Z Elevation	Water Level (mamsl)	Water Level (mbgl)
-19857.49	-3099114.19	BH23	1355.91	1353.41	2.50
-11941.51	-3102231.24	BH24	1383.67	1378.97	4.70
-12187.50	-3101793.20	BH25	1389.43	1383.83	5.60
-9267.98	-3110772.90	BH25H	1313.51	1298.51	15.00
-15815.92	-3101350.37	BH27	1370.42	1368.72	1.70
-13010.11	-3102010.40	BH28	1382.44	1381.04	1.40
-13232.48	-3097391.12	BH29	1388.73	1384.91	3.82
-16383.81	-3105943.66	BH2H	1334.59	1334.37	0.22
-22799.24	-3104631.11	BH30	1347.03	1344.90	2.13
-19613.19	-3102470.31	BH31	1349.38	1348.08	1.30
-20898.97	-3096804.37	BH32	1363.37	1361.17	2.20
-17348.24	-3100192.80	BH33	1364.29	1361.29	3.00
-13723.14	-3097422.67	BH35	1383.30	1369.10	14.20
-17853.13	-3098375.87	BH36	1359.47	1357.47	2.00
-23628.94	-3092446.56	BH37	1386.71	1376.36	10.35
-25556.48	-3092531.12	BH38	1384.31	1378.83	5.48
-25569.45	-3092551.84	BH39	1384.09	1380.89	3.20
-31904.27	-3091973.03	BH40	1333.61	1330.21	3.40
-33442.29	-3090619.50	BH41	1338.13	1332.13	6.00
-30444.79	-3092781.88	BH42	1337.84	1335.04	2.80
-31827.65	-3091518.78	BH43	1336.39	1329.89	6.50
-20127.75	-3098828.36	BH44	1354.54	1351.84	2.70
-33645.18	-3091118.50	BH45	1336.07	1327.27	8.80
-32432.29	-3093627.78	BH46	1327.18	1324.58	2.60
-34436.68	-3092600.56	BH47	1329.91	1323.91	6.00
-34649.06	-3096249.44	BH48	1328.76	1324.16	4.60
-50816.41	-3092949.82	BH51	1296.92	1293.72	3.20
-51129.20	-3092896.43	BH52	1295.84	1277.80	18.04
-32061.12	-3096603.98	BH55	1337.22	1331.36	5.86
-17944.18	-3108876.89	BH59	1315.26	1311.56	3.70
-17678.67	-3108347.22	BH60	1321.40	1314.10	7.30
-17101.75	-3108248.29	BH61	1313.47	1311.67	1.80
-12465.18	-3091866.88	BH63	1391.42	1389.29	2.13
-18008.82	-3108959.15	BH65	1312.62	1309.52	3.10
-17094.60	-3108234.53	BH66	1313.24	1306.84	6.40
-17913.00	-3109126.06	BH68	1300.50	1293.10	7.40
-17782.13	-3109128.64	BH69	1299.08	1295.48	3.60
-32389.06	-3094985.26	BH70	1330.40	1330.40	0.00
-32641.36	-3080887.13	BH72	1324.89	1310.39	14.50
-41344.55	-3092653.31	BH73	1312.84	1298.30	14.54
-41814.24	-3092422.29	BH74	1307.85	1293.14	14.71
-41471.33	-3091989.43	BH75	1313.93	1307.30	6.63
-42855.17	-3092211.33	BH76	1304.72	1292.04	12.68
-43306.87	-3092176.22	BH77	1305.15	1292.65	12.50
-42955.37	-3094589.14	BH78	1301.32	1297.64	3.68
-13842.78	-3116697.48	BH89H	1376.39	1356.38	20.01
-13074.28	-3116029.65	BH91H	1371.56	1364.16	7.40
-13760.13	-3118665.88	BH93H	1382.80	1381.00	1.80
-42477.80	-3092336.01	BH96	1303.94	1293.64	10.30
-15726.64	-3127795.87	J1	1365.13	1359.03	6.10

X Co-ordinate (m) Cape LO27	Y Co-ordinate (m) Cape LO27	Borehole Identification Number	Z Elevation	Water Level (mamsl)	Water Level (mbgl)
-15634.03	-3127292.21	J11	1354.55	1344.85	9.70
-15531.75	-3127112.25	J2	1352.87	1346.57	6.30
-16496.39	-3129938.08	J5	1393.04	1385.15	7.89
-17799.33	-3129299.22	KLM1	1406.30	1397.70	8.60
-16550.51	-3127445.59	KLM2	1371.58	1370.78	0.80
-15926.97	-3127403.20	KLM3	1360.68	1357.68	3.00
-15690.02	-3128636.36	KLM4	1377.44	1369.34	8.10
-12171.99	-3104227.65	P5	1362.04	1358.84	3.20
-12942.94	-3104234.62	P7	1363.47	1356.37	7.10
-29479.00	-3101851.00	STHH2	1330.52	1329.72	0.80
-29107.00	-3101333.00	STHH3	1336.86	1335.36	1.50
-29333.00	-3100795.00	STHH4	1345.64	1343.44	2.20
-29663.00	-3102809.00	STHM2	1326.33	1325.23	1.10
-29718.00	-3102578.00	STHM3	1325.82	1325.02	0.80
-30768.00	-3102813.00	STHM4	1322.29	1320.09	2.20
-33408.98	-3071710.11	VP2	1308.76	1308.54	0.22

4.3 Borehole Yields

No knowledge with regards to the yields of the monitoring boreholes depicted in Table 4-1 is available. The typical range of yields recorded from boreholes drilled into the Karoo geological formations as reported by van Niekerk (1991) is depicted in Table 4-3.

Table 4-3 Borehole Yields Encountered in the Welkom Area

GEOLOGICAL FORMATION	BOREHOLE YIELDS
BEAUFORT GROUP	0.0 – 10m³/hour
ECCA GROUP	0.0 – 1.5m³/hour
DOLERITE INTRUSIONS	0.4 – 15m³/hour
FRACTURES	0.4 – 15m³/hour

4.4 Groundwater Level vs. Topography

Water levels across the study area mimic the surface topography to a considerable extent. This can be observed in Figure 4-9 where the water level elevations measured in the observation boreholes for Harmony Welkom are correlated with the corresponding surface elevations. A very strong correlation coefficient of 98.5% is obtained between these two parameters.

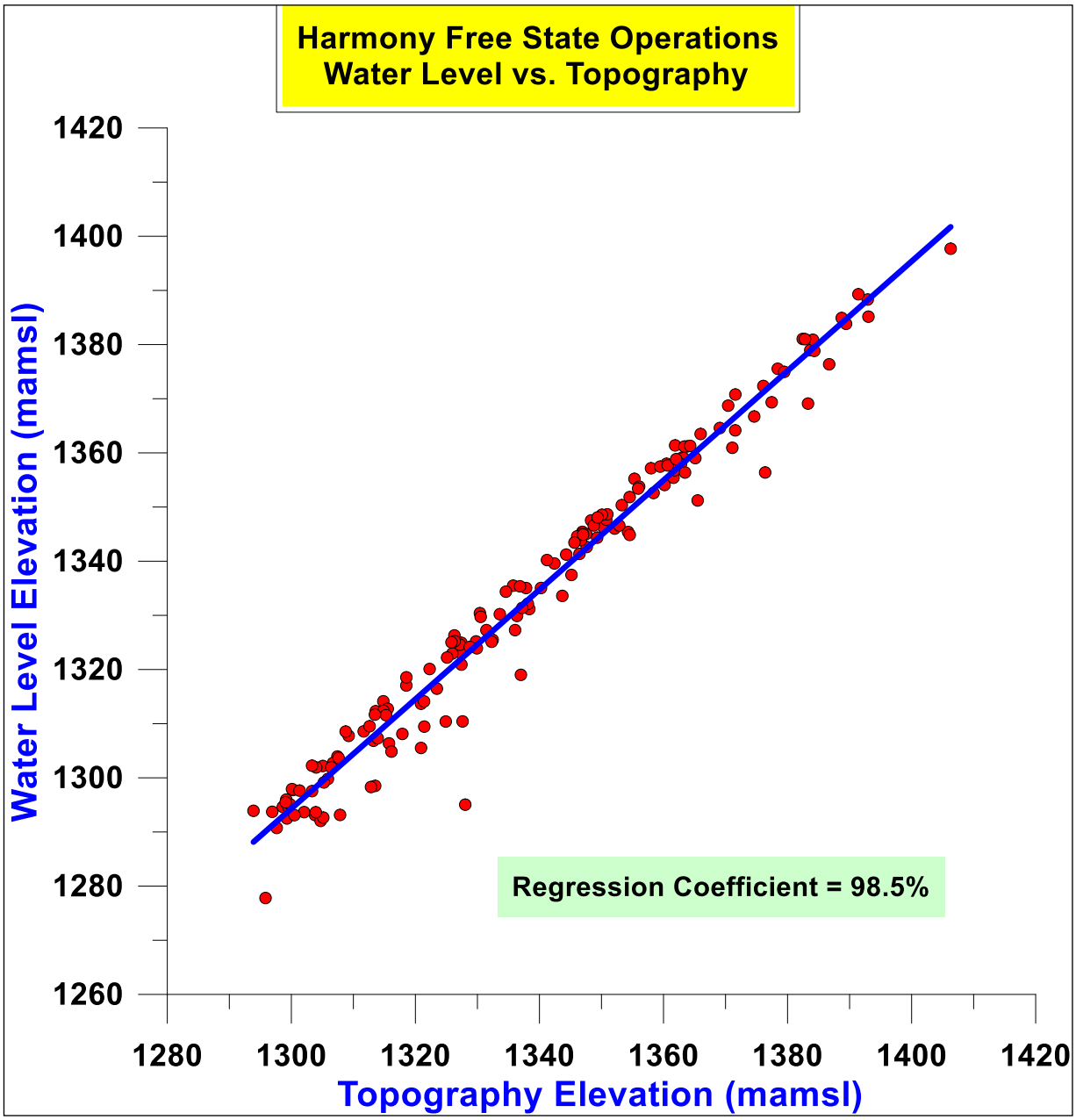


Figure 4-9 Welkom Harmony – Water Level vs. Topography.

4.5 Depth to Water Table(s)

The depth to the water table across the study area varies between zero and 33 metres below ground level. Figure 4-10 shows the frequency histogram depicting the depth to the groundwater level below surface. From the frequency histogram, it is evident that the data is log-normally distributed. Average depth to water level below surface is 5.28m. The median value is 4.00m. From the graph, it is further evident that the highest frequency is in the interval 0-4 metres below ground surface.

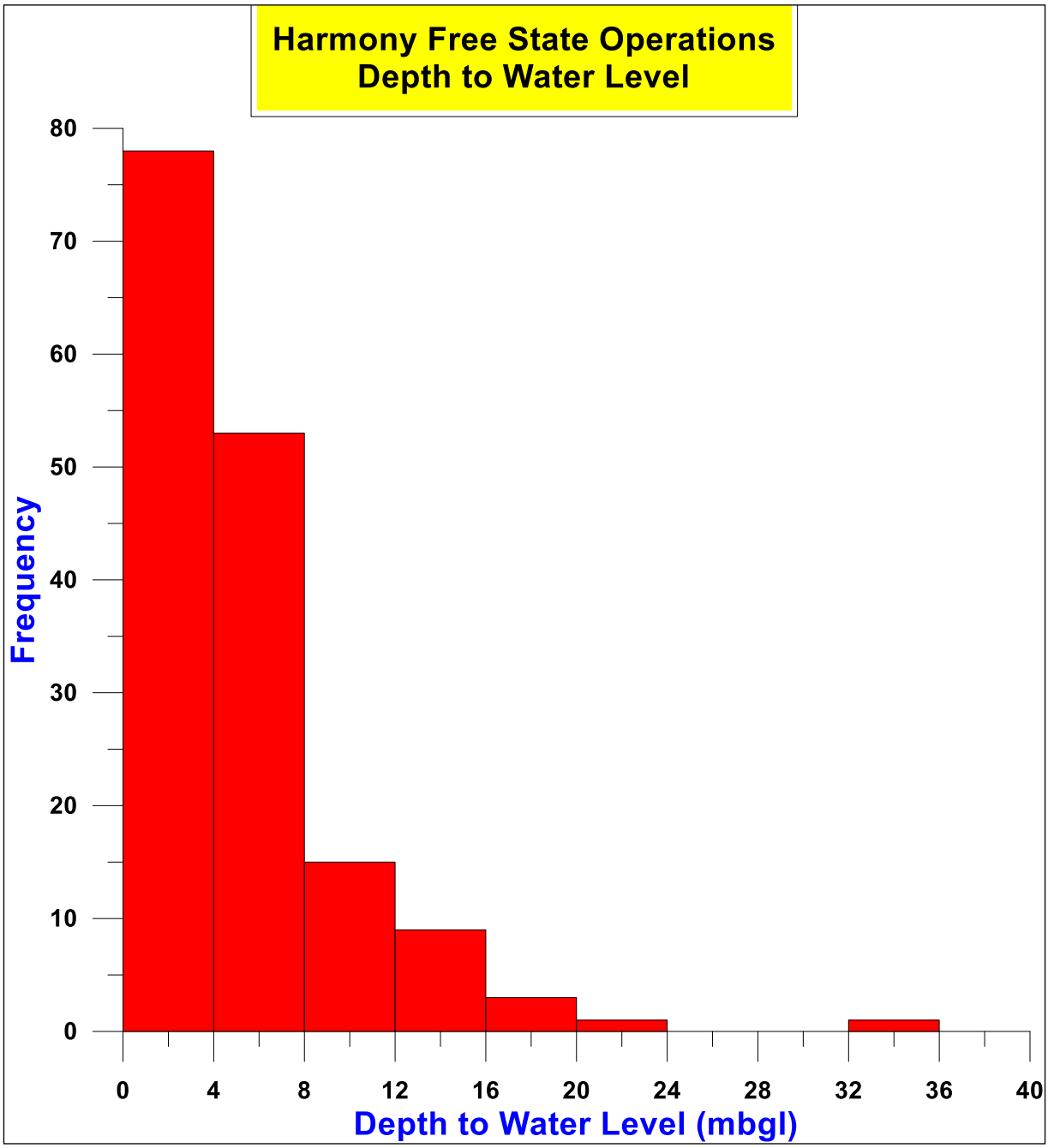


Figure 4-10 Welkom Harmony – Depth to Water Level Frequency Distribution.

4.6 Groundwater Level Contours, Flow Directions and Groundwater Fluctuations

4.6.1 Groundwater Level Contours

Groundwater level elevation contours were prepared from groundwater level monitoring data of the data sets available. These contours are depicted in Figure 4-11. According to the groundwater level elevations groundwater flows along the natural drainages of the various sub-catchments and flow conforms to the surface water drainage. The observed groundwater levels will be used for steady state model calibration.

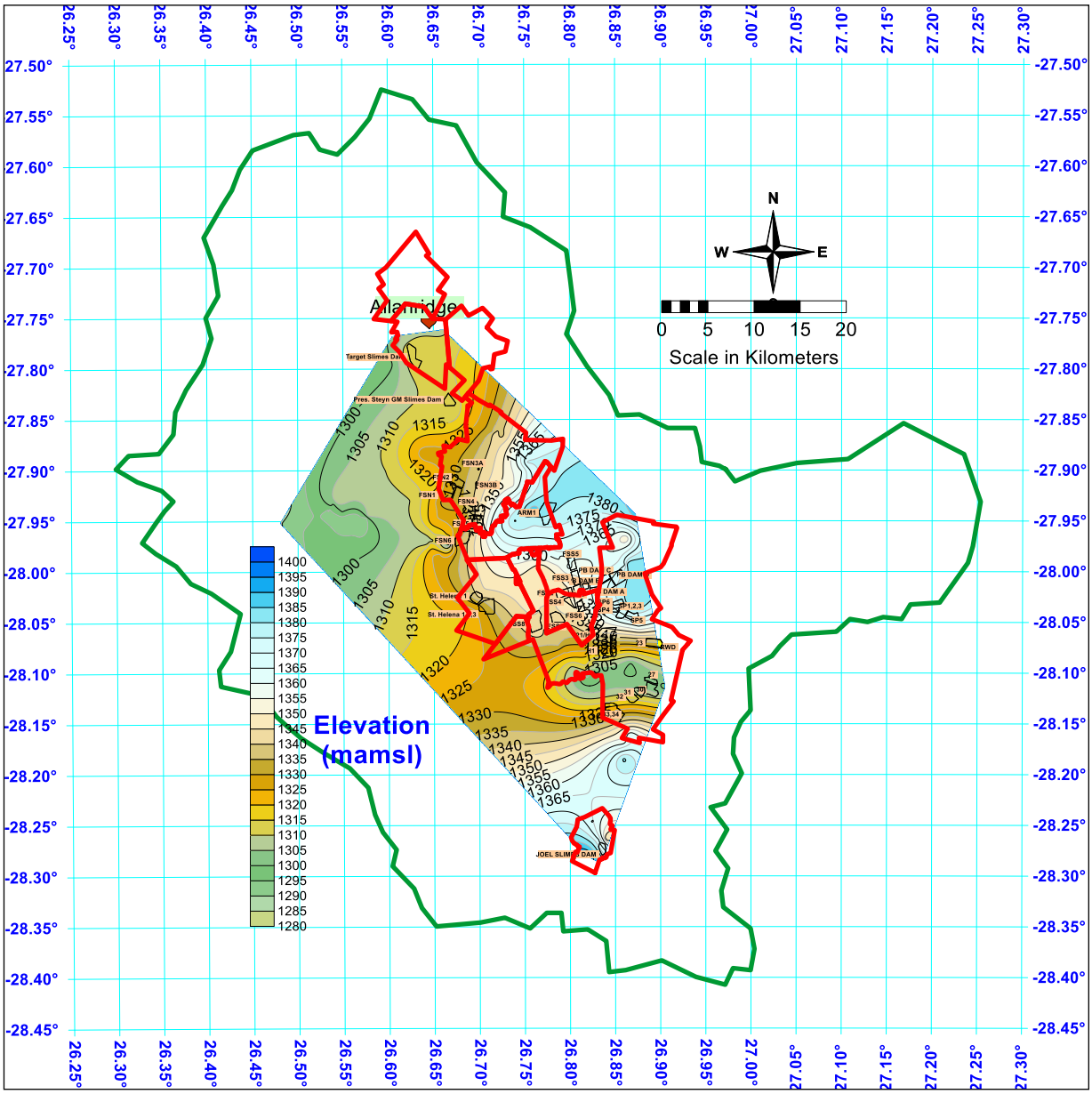


Figure 4-11 Observed Groundwater Flow Contours.

4.6.2 Groundwater Flow Directions

Groundwater flow directions are indicated on Figure 4-12 by the red arrows. According to this map groundwater flow is to the northwest in the Target area (along the Sand Spruit), along the Mahem Spruit and to the Dankbaar Pan in the west, to the Doring Pan in the northeast of the study area, to south towards the Sand River (north of the Sand River), to the north (south of the Sand River, and to the north along the Doring River in the south at Joel Mine. According to the contour shapes Wit Pan is also a receiving (gaining) feature in terms of groundwater movement.

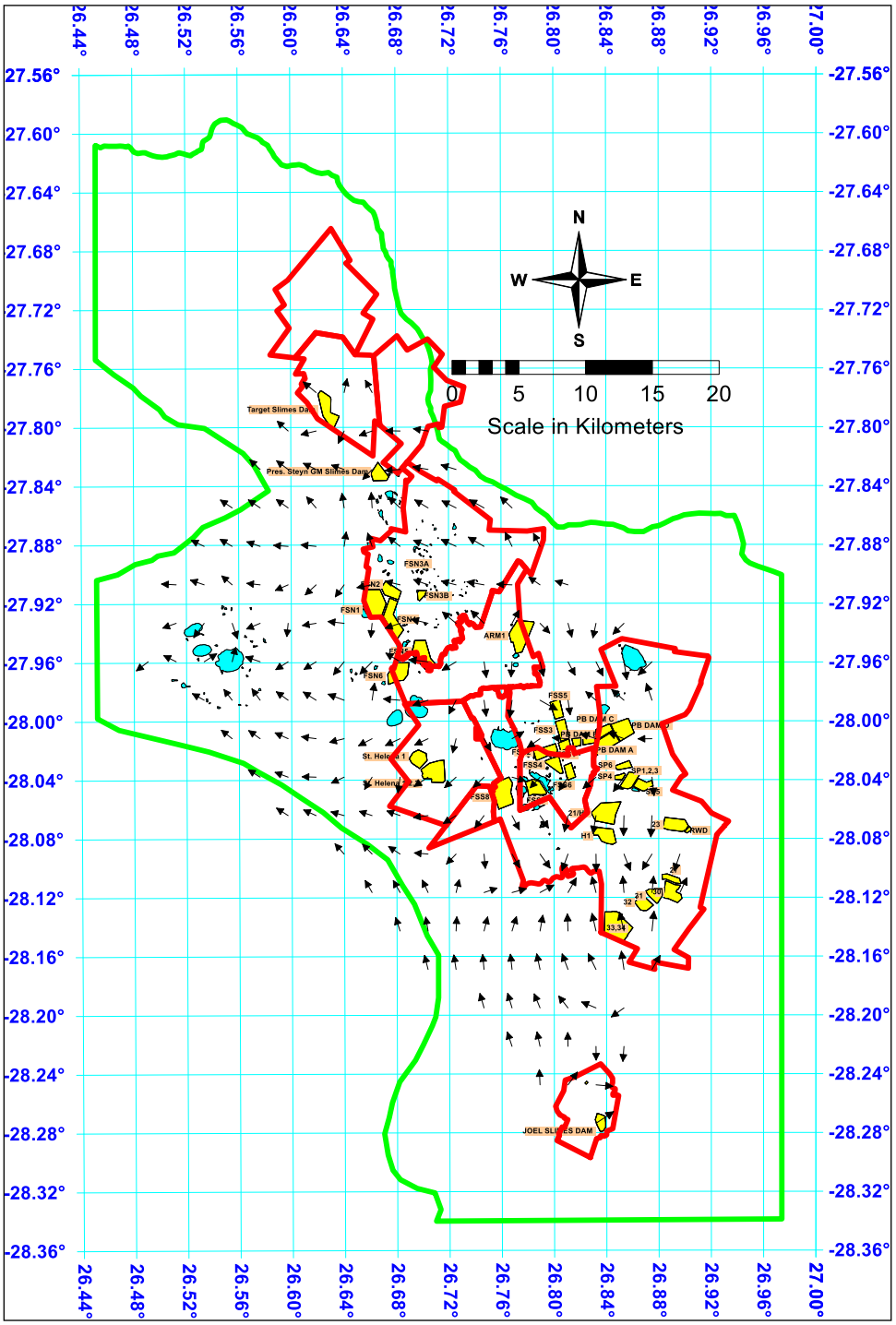


Figure 4-12 Groundwater Flow Directions indicated by black Arrows.

4.6.3 Groundwater Fluctuations

Groundwater fluctuations of boreholes where long-term water levels were observed are depicted in Appendix I. In the compilation of the water level fluctuation graphs the data collected by AngloGold at the time when they owned the mining operation were added to the data collected by Harmony. Graphs are therefore depicting all data collected by AngloGold and Harmony.

Typical long-term water level fluctuations observed in boreholes are presented in Figure 4-13 to Figure 4-17. From the water level fluctuations presented it is evident that the fluctuations are

relatively small (within a metre or two up or down seasonally). It is further evident that no distinctive trends – up or down – can be distinguished which indicates to quasi-steady state flow conditions.

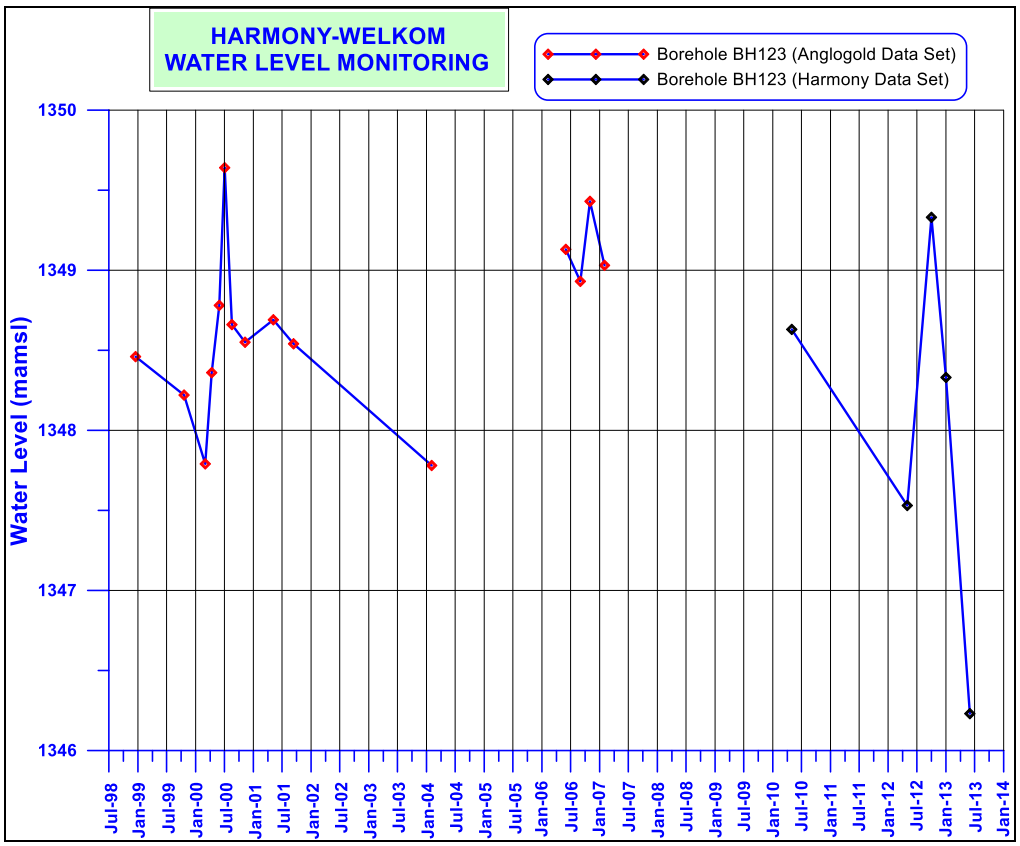


Figure 4-13 Long-term water level fluctuations observed at Borehole BH 123.

4.7 Groundwater Abstraction

No large-scale groundwater abstraction occurs from the system.

4.8 Hydraulic Tests and Aquifer Parameters

Aquifer tests are usually conducted to determine aquifer hydraulic parameters (transmissivity, hydraulic conductivity, and storativity). These data are essential for the numerical flow modelling exercise.

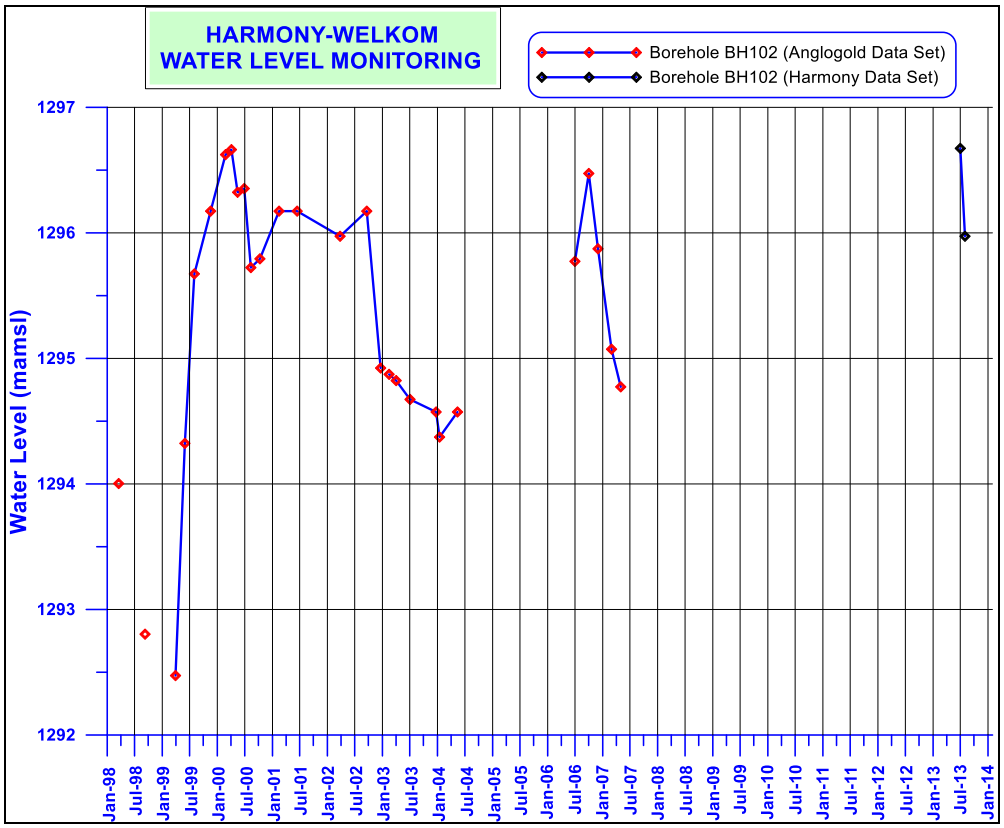


Figure 4-14 Long-term water level fluctuations observed at Borehole BH 102.

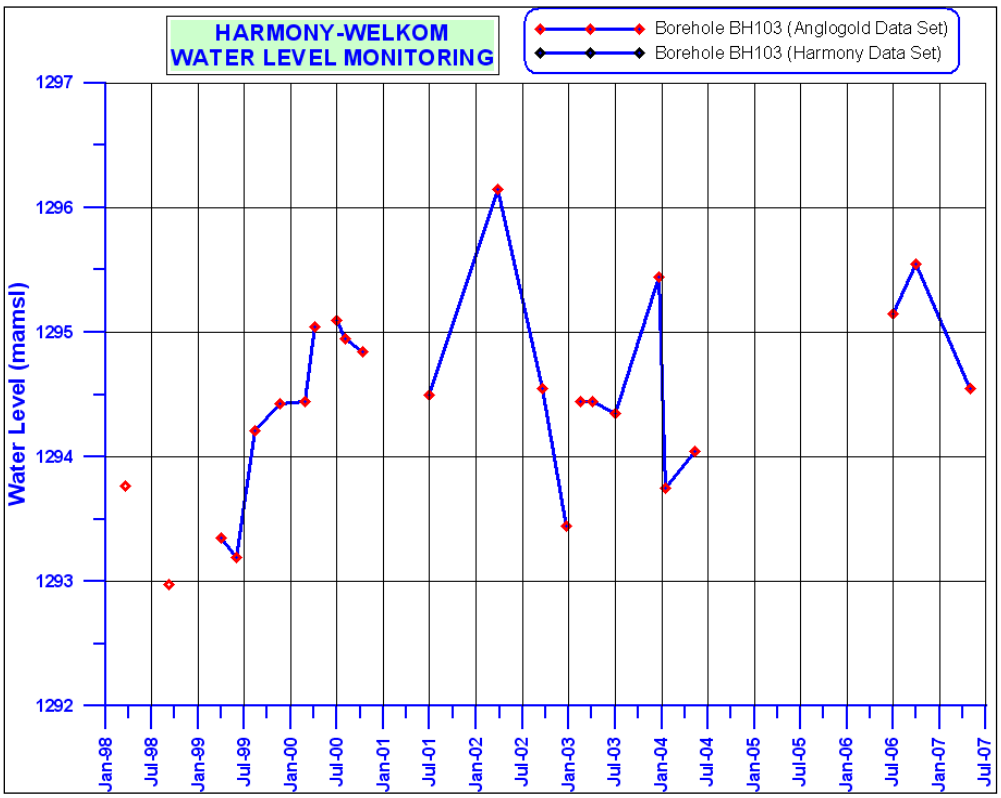


Figure 4-15 Long-term water level fluctuations observed at Borehole BH 103.

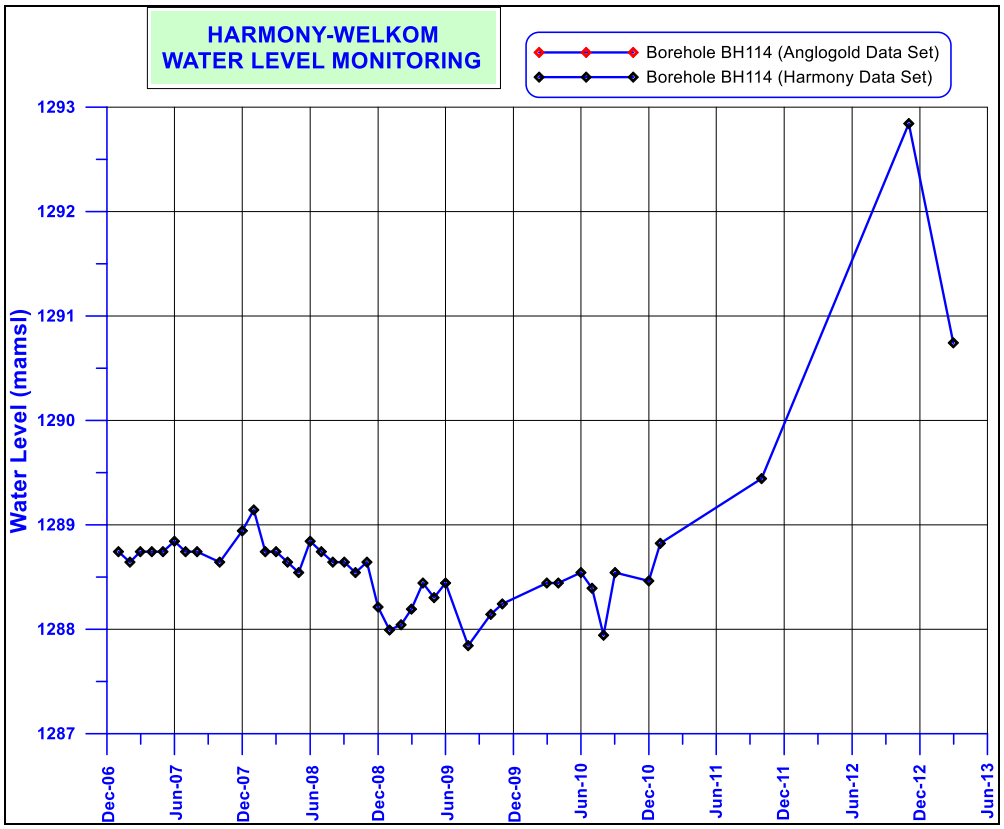


Figure 4-16 Long-term water level fluctuations observed at Borehole BH 114.

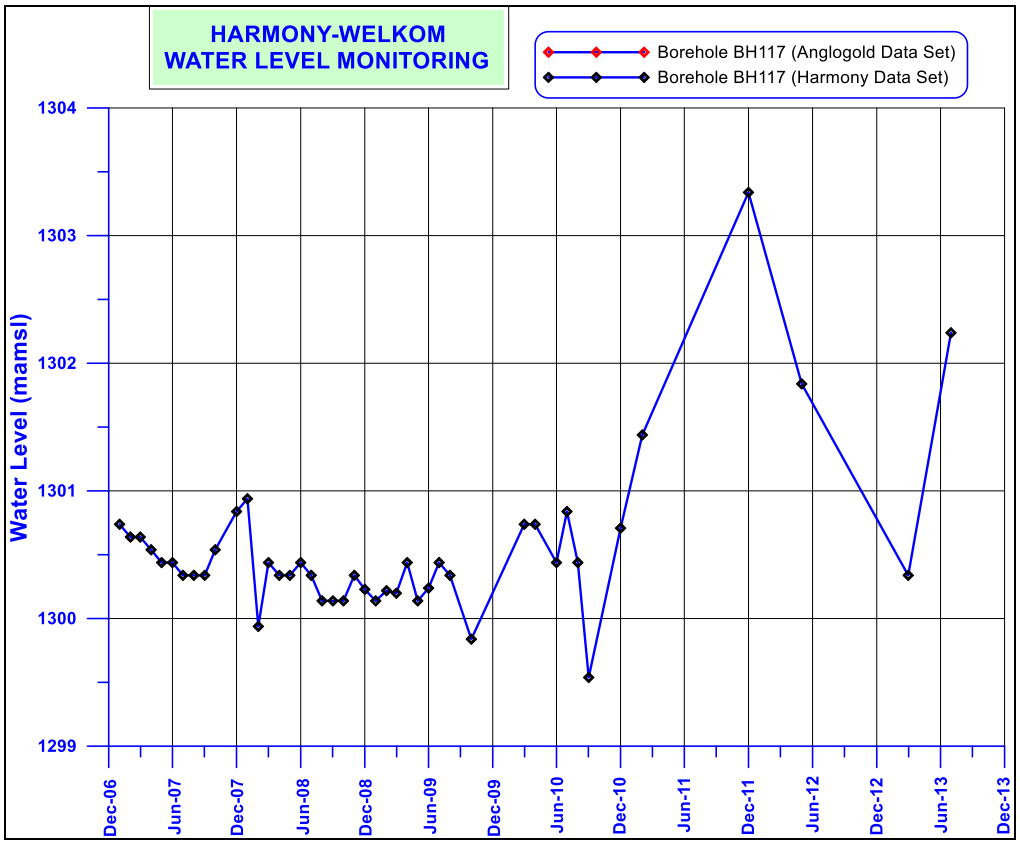


Figure 4-17 Long-term water level fluctuations observed at Borehole BH 117.

4.8.1 Aquifer Transmissivity

Aquifer transmissivity can be defined as the rate of flow of water in cubic metres per day through a unit width of aquifer under a unit hydraulic gradient (Units: m^3/day/m or m^2/day).

4.8.2 Hydraulic Conductivity

Hydraulic conductivity can be defined as the rate of flow of water in cubic metres per day through a cross section of one square metre of aquifer under a unit hydraulic gradient (Units: m^3/day/m^2 or m/day). Estimates of the hydraulic conductivity of the aquifer can be obtained from the results of constant rate tests conducted during a field exploration programme and dividing the saturated thickness into the calculated T-values since T=KD.

4.8.3 Aquifer Storativity

[Definition of Storage Coefficient: Specific storage (S_o) times aquifer thickness (B). The volume of water an aquifer release from or takes into storage per unit surface area of the aquifer per unit change in head.]

[Definition of Specific Yield: The volume of water an aquifer releases from storage per unit surface area of the aquifer per unit change in head under gravity.]

Secondary porosity is present as a result of the weathering and fracturing processes the rocks underwent. An estimate of the aquifer storativity (storage coefficient) was obtained from generally accepted values for hard rock aquifers ($6x10^{-3}$).

4.8.4 Hydraulic parameters for aquifer(s) in the Harmony Welkom Study area

Aquifer tests that could be located during the desk study phase of this project included tests conducted by Golder (2008). Aquifer tests were analysed using different methods of evaluation suitable for the specific criteria of the tests. Table 4-4 shows the transmissivity and hydraulic conductivity values obtained for the Harmony Welkom Study Area from the aquifer tests conducted by Golder (2008) and some field data sets obtained from Golders (2008) and analysed by Aquisim Consulting during this investigation (Appendix II and Table 4-5). The heterogeneous nature of the aquifer is evident from the variability in the calculated transmissivity/hydraulic conductivity values. This behaviour is typical for fractured and weathered sedimentary hard rock aquifers. The very low T- and K-values are indicative of a very low permeable environment.

Table 4-4 Transmissivity values analysed from field data sets obtained from Golder (2008).

Borehole Number	*Transmissivity (m^2/day)*
8788-01	1.61
8788-02	1.12
8788-03	$3.09x10^{-1}$
8788-09	$3.96x10^{-1}$
8788-10	$5.94x10^{-2}$
8788-11	$7.06x10^{-1}$
8788-12	$2.94x10^{-2}$
8788-19	$1.26x10^{-2}$
8788-11	$1.36x10^{-2}$

Figure 4-18 shows the frequency histogram for the transmissivity distribution obtained for the Harmony Welkom Study Area using the data sets from Golder (2008) investigation. The data set is

log-normally distributed.

Table 4-5 Summary of pump tests and estimated aquifer parameters (Verbatim from Golder, 2008).

BH ID	SWL	Collar	Corrected SWL	BH Depth	Corrected BH Depth	Saturated Thickness	T (Drawdown)	T (Recovery)	T (Average)	K
	mbc	magl	mbs	mbc	mbgl	m	m2/day	m2/day	m2/day	m/day
BH129	2.9	0	2.90	26.24	26.24	23.34	14.30	14.60	14.45	0.619
BH135	2.88	0	2.88	35.95	35.95	33.07	2.50	3.10	2.80	0.085
BH41	6.06	0.28	5.78	26.37	26.09	20.31	27.60	-	27.60	1.359
BH144	19.49	0.71	18.78	39.19	38.48	19.70	0.70	-	0.70	0.036
BH120	0.72	0.27	0.45	20.36	20.09	19.64	1.20	-	1.20	0.061
BH190	2.24	0.14	2.10	28.24	28.10	26.00	0.60	-	0.60	0.023
BH142	8.09	0.56	7.53	35.74	35.18	27.65	0.50	-	0.50	0.018
BH17	2.32	0	2.32	35.20	35.20	32.88	1.90	-	1.90	0.058
H3-1	7.49	0.48	7.01	100.00	99.52	92.51	1.70	-	1.70	0.018
BH122	2.36	0.45	1.91	30.35	29.90	27.99	8.00	8.40	8.20	0.293
BH123	1.59	0.43	1.16	26.46	26.03	24.87	2.00	2.90	2.45	0.099
BH185	1.01	0.26	0.75	39.16	38.90	38.15	0.40	-	0.40	0.010
BH27	2.69	0	2.69	32.69	32.69	30.00	12.40	-	12.40	0.413
H3-2	5.25	0.26	4.99	35.80	35.54	30.55	2.10	3.20	2.65	0.087
N32-1	3.37	0.38	2.99	14.33	13.95	10.96	3.80	-	3.80	0.347
BH187	2.84	0.66	2.18	25.42	24.76	22.58	0.50	-	0.50	0.022
SH-1	5.78	0.21	5.57	25.40	25.19	19.62	28.00	-	28.00	1.427

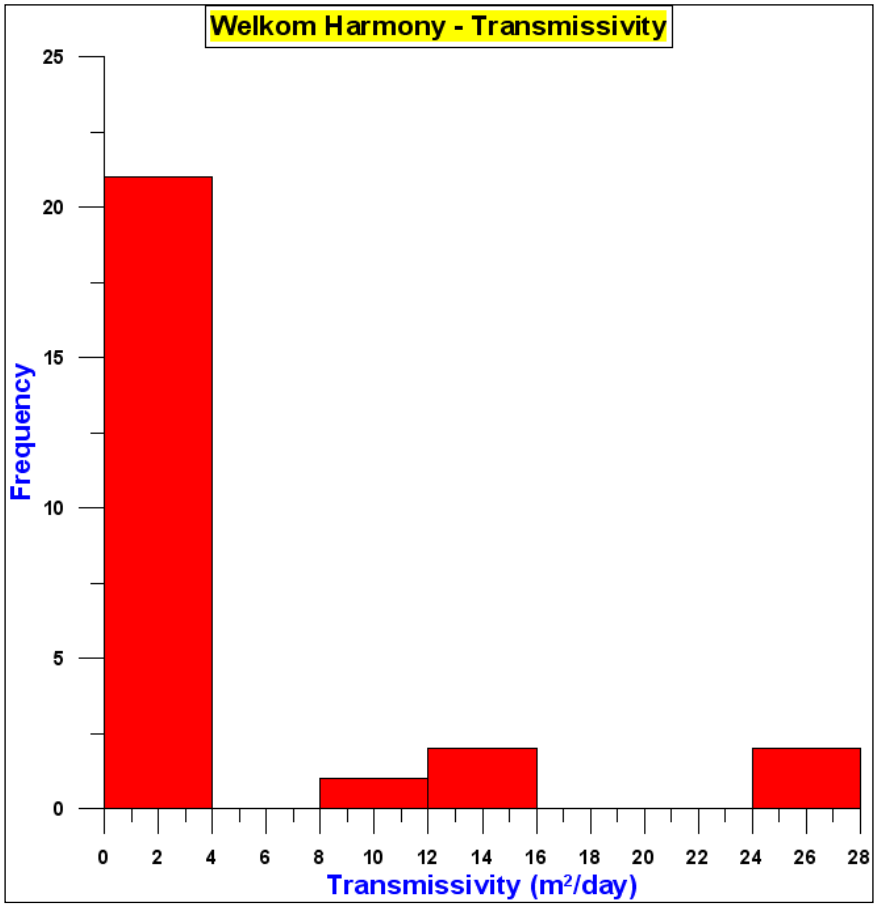


Figure 4-18 Frequency Histogram for Transmissivity Harmony Welkom using the Golder (2008) data sets.

5 Groundwater Flow Model Development

5.1 Conceptual Model of the Aquifer System (Key Concept)

The first step in the modelling procedure is the construction of a conceptual model of the problem and the relevant aquifer domain. The conceptual model consists of *a set of assumptions* that reduce the real problem and the real domain to simplified versions that are acceptable in view of the objectives of the modelling and of the associated management problem.

The data gathered during the desk study and data evaluation phase of the study has been used to develop a hydrogeological conceptual model for the area, which forms the basis for the numerical modelling. The conceptual model is outlined below.

In a typical hydrogeological setting groundwater flow and aquifer development are closely linked to the geology and structural geology of an area. There is no reason to believe that the area under investigation will not conform to this assumption and therefore the surface geology as depicted in Figure 3-1 forms the basis on which the conceptual hydrogeological model is based spatially. The nature and distribution of the geological units, and possibly geological structures control the hydrogeology of the study area. The aquifer(s) underlying the study area consist(s) mainly of hard rock aquifers associated with the Karoo Sequence sandstone, siltstone and shale.

5.1.1 Aquifers

According to Golder (2008), two main aquifers exist in the area; these are (a) a shallow aquifer associated within the weathered and fractured zone of the Karoo lithologies, and (b) a deeper aquifer which is developed in the fractured and faulted Ventersdorp and Witwatersrand rocks.

Shallow Karoo aquifer: It is known that in similar geological terrains a relationship exists between the groundwater table and the topography. This relationship, which is known as the Bayesian relationship assumes that the groundwater table mimics the topography. This relationship was confirmed by plotting topographic elevation against groundwater elevation. A strong relationship exists between topography and groundwater level as indicated by a 99% correlation (Figure 4-9). This means that flow takes place towards low points in the topography, which are occupied by pans and watercourses. The strong correlation between topography and groundwater elevation also implies that negligible vertical leakage occurs between the shallow and deep aquifer systems.

Deep fractured aquifer: The deep aquifer occurs in the fractured rocks of the Witwatersrand and Ventersdorp Supergroups which are located hundreds of meters below surface. This aquifer is confined by the thick sequence of overburden. The yield of the deep aquifer is highly dependent upon geological structures, with flow occurring predominantly along faults, fractures and intrusive contact zones.

Pumping from the deep aquifer system was initiated across the Free State Gold Fields in 1952 in order to dewater working areas. Rest water levels have declined by hundreds of meters since dewatering was initiated. However, no corresponding drop in water levels within the shallow aquifer has been noted as a response to dewatering, providing further evidence that the shallow and deep aquifer systems are not hydraulically connected. The extreme depth of the aquifer and the low permeability of the confining strata ensure that this aquifer receives minimal recharge, which has contributed to the progressive deterioration of water quality within this aquifer (Harmony Saaiplaas EMPR, 2002). The origin of groundwater within the deep aquifer is less well understood but is thought to be connate (original formation water) or extremely old (fossil) and is usually concentrated on

geological structures such as fault zones or igneous intrusions (e.g. dykes).

5.1.2 Type of Aquifer

The shallow Karoo aquifer is the prime focus of this investigation as it has been shown that no hydraulic connection exists between the shallow (the Karoo aquifer) and deeper aquifer of the Ventersdorp and Witwatersrand Supergroups.

The shallow Karoo aquifer can be further sub-divided into two units namely a shallow weathered aquifer and a deeper fractured hard rock aquifer.

Shallow Weathered Aquifer

This aquifer is usually confined to semi-confined and is recharged by rainfall. The water level is often perched and because of the impermeable shale horizons may even be artesian in places, hence the many natural springs and/or wetlands. The recharge to this aquifer is estimated to be in the order of 3% of the annual rainfall (Hodgson & Krantz, 1998). The numerous shale layers in these formations often restrict the downward filtration of rainwater into the aquifer. The largest accumulation of water is normally confined to the contact between the weathered and "fresh" bedrock. The borehole yields in this aquifer are generally low due to the very low aquifer parameters of the aquifer material. The groundwater quality in undisturbed areas is good due to the dynamic recharge from rainfall. This aquifer is, however, more likely to be affected by contaminant sources situated on surface, an aspect that will be discussed in more detail later in this report.

Deeper Fractured Aquifer

The primary permeability of the Ecca Group rocks does not allow significant groundwater flow, except where the permeability has been increased by subsequent secondary structures. Groundwater flow in the fractured aquifer is often associated with the abundant dolerite dykes and sills in the area. The intrusion of dykes and sills caused the surrounding rock to fracture and although not all these fractures are necessarily water bearing, it has created additional conduits. The presence of dykes is fairly easy to identify in the field as well as the edges, with which the bulk of the fractures are associated, but individual fractures are more difficult to identify and require sophisticated geophysical techniques to identify them.

Although occasional high yielding boreholes may be intersected, this aquifer also does not constitute an economic aquifer able to sustain excessive pumping and irrigation. The groundwater quality in the fractured aquifer is generally of a poorer quality than the weathered aquifer due to the concentration of salts and slower rate of recharge. This may be attributed to a less dynamic system and a larger residence time of rainfall recharge within the aquifer. According to Hodgson and Krantz (1998) the coal seams often show the highest hydraulic conductivity.

The following statistics were established from drilling 43 exploration holes (Golder, 2008):

1. Average thickness of Karoo: 117 m

2. Percentage of boreholes intersecting dolerite in Karoo: 33%

3. Average depth of dolerite from surface: 74 m

Unfortunately, water strike positions and yields were not recorded during the past. The more recent drilling has confirmed that groundwater occurs in two predominant places. These are on the contact zones with dolerite intrusions and on the lithological contact between the Karoo sediments and the Ventersdorp lavas. Measured yields vary from 0.1 L/s to 22 L/s in exceptional cases.

These yields substantiate the statement that borehole yields are structurally controlled and that groundwater yields are generally poor within the Ecca Formation. The yields of farmers boreholes in the immediate vicinity of the mine are less well known.

Pretorius (1989) drilled 39 additional boreholes across the Free State goldfields. The yields of boreholes drilled during his investigation are summarised in Table 5-1.

Table 5-1 Summary of boreholes drilled in the Beaufort and Ecca Groups.

Aquifer	Dry Boreholes (% of total drilled)	Average Yield (m^3/hr)	Average Yield of boreholes with water strikes (m^3/hr)
Beaufort Group (Adelaide Subgroup)	25	2.7	3.55
Ecca Group (Volksrust Formation)	42	0.92	1.58

This table illustrates that the boreholes drilled demonstrate the following characteristics of shallow aquifer:

- Boreholes which tap the Beaufort group are generally higher yielding than those which are sited on the Ecca Group.
- Borehole yields are consistently highest in boreholes that encounter dolerite due to the development of interconnected fracture networks in the contact zone.
- 10 of the 26 boreholes drilled in either sandstone or shale were dry. By contrast only 2 of the 13 boreholes in which dolerite was encountered were dry.

In boreholes which did not encounter dolerite, water strikes generally occurred on the contact between sandstone and shale.

It has been noted that boreholes intersecting superficial deposits of gravel and sand which have developed along water courses and paleo-drainage features generally have moderate yields higher than those encountered in boreholes located in Beaufort and Ecca Groups.

5.1.3 Aquifer Depths

Depth of shallow aquifer: The regional groundwater gradient is predominantly to the west. Groundwater levels typically follow the topography in the region. The groundwater level is found to be on average at a depth of around 10 m below ground level. During the hydrocensus most SWL's were shallower than 3 m below surface. Shallow water levels also explain the occurrence of many natural pans in the area.

Depth of deep aquifer: The depth of the fossil aquifer associated with the Witwatersrand rocks was approximated with a finite element simulation program by the WRC to be 300m below surface. Mining prospecting boreholes indicated this level to be between 170-270 m.

The original occurrence of artesian water intersections and the subsequent self-evident development of two distinctly separate water tables within the Welkom Goldfields have to be based on the existence of a persistent impervious layer. Considering the fact that the early artesian intersections were always associated with pre-Karoo rocks and the fact that the layers of the Ecca Group represent the only persistent stratigraphic zone in the required position, it has to be accepted that this group represents the impervious layer responsible for the development of artesian conditions. It need hardly be emphasized that the relatively undisturbed, impervious and incompetent nature of the shales of

the Ecca Group result in this zone being an ideal barrier between the two water systems. The only possible alternative would be the Ventersdorp Supergroup, but this possibility may be eliminated without reservation on the grounds that many artesian intersections occurred within this zone and that layers of this group are, by far, too limited in their aerial distribution to explain the observed facts (Bekker, 1986).

5.2 General Regional Conceptual Model (Golder, 2008)

The conceptual model for the study area is based on the geological setting; hydrogeological parameters obtained from aquifer tests undertaken during previous studies as well as the groundwater flow patterns. Three aquifers are included in the conceptual model, namely a shallow perched and a deeper fractured rock aquifer within the Karoo Supergroup and a deep fractured aquifer that has developed in the Ventersdorp and Witwatersrand Supergroups:

The shallow perched aquifer is developed in the weathered zone. The depth of the weathered zone is unknown but typically extends to depths of between 2-10 metres below surface and is restricted to the soil and sub-soil horizons. The aquifer is formed by the direct recharge of rainwater that collects along the transition from weathered to fresh rock. This transition between weathered and competent rock, in places associated with clay or ferricrete, forms the base of the perched aquifer. The perched aquifer is typically unconfined or semi-confined. Groundwater levels are not available for this aquifer, but seepage was encountered within the first 2 – 3 m in auger holes. It is anticipated that the static water level in this aquifer would be like those measured in the fractured rock aquifer, as discussed below. The hydraulic conductivity for this aquifer could not be calculated with available information, but typically varies between 0.001 and 0.1 m/d.

From previous experience, the hydraulic conductivity of the soil underlying the existing tailings dams is thought to be in the region of 7.06×10^{-5} to 0.006 m/d. The porosity of the perched aquifer could not be calculated with available information but is typically 3-7%. Often the perched aquifer is not laterally extensive and is therefore not considered to be a significant aquifer. However, it often contributes to the baseflow of streams.

A deeper fractured rock aquifer formed by bedding planes, fractures and faults in the weathered and competent sediments of the Beaufort and Ecca Groups is developed below the weathered aquifer. This aquifer is also replenished by rainfall recharge and will be semi-confined to confined in nature. There is insufficient information available to calculate the storage coefficient, but values of 1×10^{-5} to 1×10^{-2} are typical of Karoo aquifers. The porosity for the fractured rock aquifer could not be calculated from available information, but it is typically in the order of 1-3%. The depth of groundwater, based on monitoring borehole information, in this aquifer is like the perched aquifer and is often less than 0.5m below surface. This suggests that the two aquifers are interconnected and that groundwater seeps from the perched aquifer into the fractured rock aquifer. The saturated thickness of the fractured rock aquifer is typically 10−80 m.

5.3 Groundwater System Geometry

As a result of local recharge and discharge, groundwater divides developed approximately beneath the major surface water divides. Evidence of this is provided by the correlation between groundwater level elevation and topography and the groundwater flow directions (depicted in Figure 4-9). Some of Harmony's tailings infrastructure also straddles various sub-catchment divides and it is logical therefore to include large areas of the surface water sub-catchments of the Sand Spruit, Mahem Spruit, Sand River, Doring River, Merrie Spruit and Riet Spruit into the modelling domain.

The vertical extent of the groundwater system is determined from the drilling results (Golder, 2008).

The boreholes indicate a maximum weathering depth of about 10m and fracturing depth up to 80m below surface. The model will be calibrated using the water level elevations, which are a function of the product of the saturated aquifer thickness, the hydraulic conductivity (transmissivity) and effective aquifer recharge. Should the average aquifer thickness therefore be under/overestimated is be compensated for by adjustment of the hydraulic conductivity values during model calibration.

5.4 Area of Modelling and System Boundaries

In the absence of evidence of physical subsurface no-flow boundaries, the modelling area was selected based on topographical control i.e. along surface catchment and sub-catchment boundaries. According to standard modelling practice, this is a reasonable approach to follow since a good correlation exists between the groundwater level elevation and the surface topography. Boundaries of the numerical model were therefore chosen to reflect the geometry of the surface water catchment system(s). The base of the model domain is set 80m below ground surface throughout the model area. Section 6.6 provides a detailed discussion of the boundary conditions and rationale for their selection.

5.5 Hydraulic Properties

From the limited available aquifer tests conducted across the study area in the boreholes drilled it is evident that hydraulic conductivity values (transmissivity) may vary by orders of magnitude both spatially and with depth. On average, the rock becomes solid below 80m from surface. The geological setting is complex as a result of the intrusion of diabase into the older rocks and faulting which may or may not be enhancing development of higher hydraulic conductivity zones.

The major hydrostratigraphic units of probably different hydraulic properties that exist within the study area are:

- Karoo Sequence (Ecca Group) sandstone, siltstone and shale.
- Post-Karoo dolerite dykes and diabase dykes.

Each of the above units required to be sub-divided into an upper weathered zone and a lower fractured zone.

5.6 Recharge, Discharge and Flow Directions

The groundwater system within the study area is largely recharged via infiltration of precipitation. It is thought that most of the groundwater recharge occurring within the study area discharges internally to the surface drainage systems via springs and discharge to the base of river drainage systems.

6 Approach to Numerical Modelling

6.1 Introduction

A numerical model was constructed to represent the conceptual groundwater system of the study area as presented above. The purpose of the model is to develop a tool that can be used to assess the potential groundwater conditions under a variety of source term and other development strategies on the Harmony properties. The main objective of the numerical model is however to determine the impact from the Harmony Welkom Operations on the groundwater regime of the area.

6.2 Software Code Selection

The code selected for conducting the modelling of the study area is FEFLOW developed by the WASY Institute for Water Resources Planning and Systems Research, Ltd. Berlin, Germany. Feflow is an interactive groundwater modelling system for three and two-dimensional, areal and cross-sectional, fluid density-coupled, thermohaline or uncoupled, variably saturated, transient or steady state flow, mass and heat transport in subsurface water resources with or without one or multiple free surfaces.

Feflow can be used efficiently to describe the spatial and temporal distribution of groundwater contaminants, to model geothermal processes, to estimate the duration and travel times of pollutants in aquifers, to plan and design remediation strategies and interception techniques, and to assist in designing alternatives and effective monitoring schemes. Since its creation in 1979 Feflow has been continuously improved. The Feflow source code is written in ANSI C/C++ and contains more than 1,1 million programme lines. Feflow is used worldwide as a high-end groundwater-modelling tool at universities, research institutes, government offices and engineering companies

6.3 Model Area

In order to include Harmony Free State Operation's entire infrastructure which consist of numerous TSF's, RWD's and WRD's into a single groundwater flow model, several surface drainage catchments had to be included into the modelling domain. Surface drainage systems which were included into the modelling domain are:

- the Sand Spruit,
- Mahem Spruit,
- Sand River,
- Doring River,
- Merrie Spruit and
- Riet Spruit.

The area depicted in Figure 6-1 forms the modelled area of approximately 4500km^2 which is substantially larger than the 2017 model (2468km^2). Model boundaries are selected along sub-catchment surface water divides.

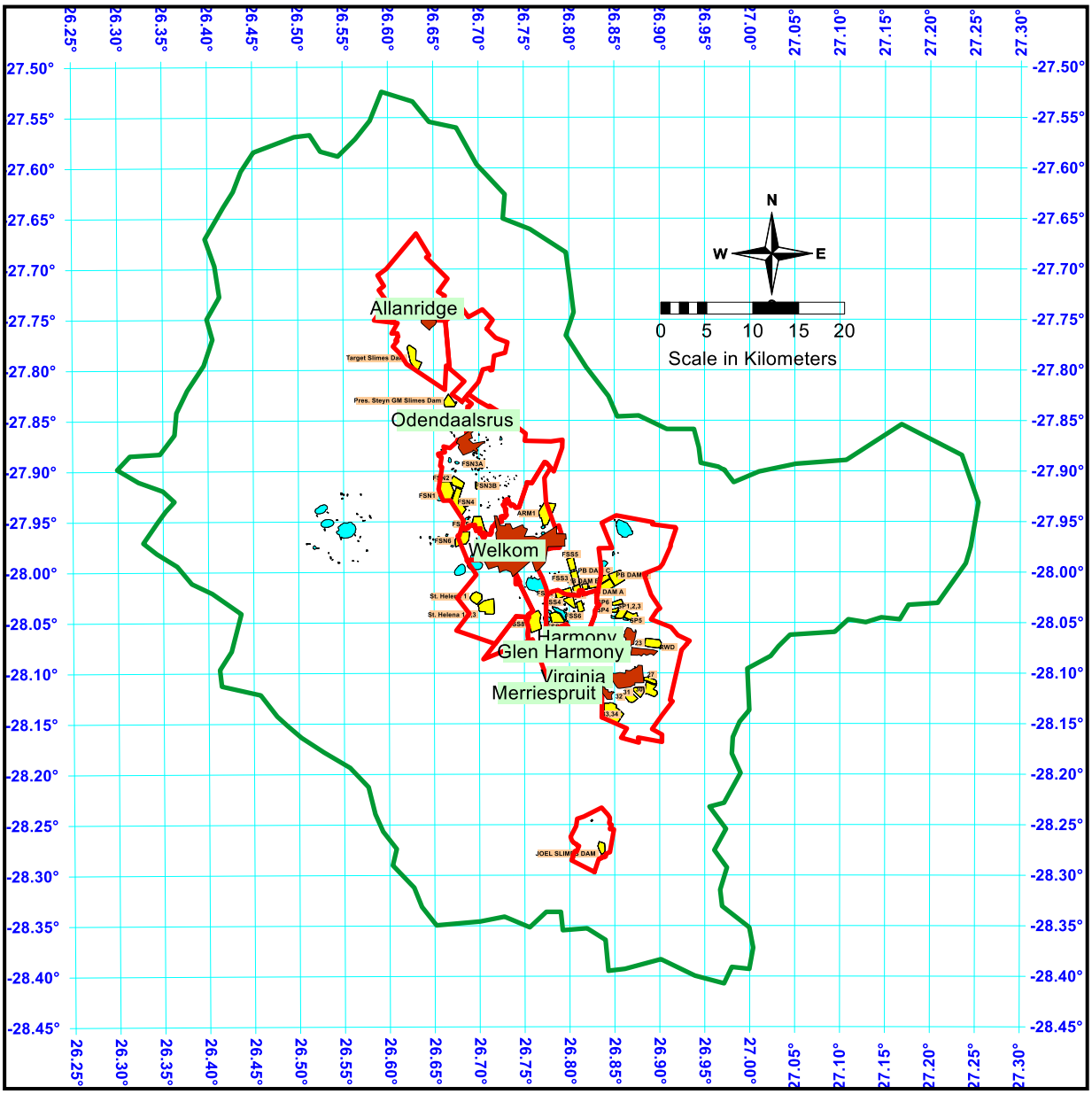


Figure 6-1 Model Domain demarcated by Green Line.

6.4 Mode of Flow

In general, flow through a porous medium is three-dimensional (Bear and Verruijt, 1992). However, since the geometry of most aquifers is such that they are thin relative to their horizontal dimensions a simpler approach can be introduced. According to this approach, vertical flow components are neglected, and we assume that the flow in the aquifer is essentially horizontal, or that it may be approximated as such. This is strictly true and not just an assumption in the case of flow in a horizontal, homogeneous, isotropic, confined aquifer of constant thickness and with fully penetrating wells. Nevertheless, the approximation is still a good one when the thickness of the aquifer varies, but in such a way that the variations are much smaller than the average thickness (Bear and Verruijt, 1992). In the case of this modelling study the aquifer is thin (a thickness of 80m is assumed respectively for the sedimentary rock relative to the modelled horizontal dimensions (90km x 50km) and a 2D-approach could therefore be adopted. Although a good case can be put forward to adopt a 2D-approach, a 3D-approach was followed whereby the aquifer was divided into two modelling layers

in order to:

- Describe the first 10m below ground elevation consisting of weathered aquifer.
- Describe the fractured aquifer down to 80m in the fractured hard rock.

6.5 Numerical Flow Model

A steady state groundwater flow model for the study area was constructed to simulate undisturbed groundwater flow conditions. These conditions serve as starting heads for the transient simulations of groundwater flow and mass transport where the effect of tailings deposition will be taken into consideration.

A dynamic flow model using the modelling package FEFLOW (Diersch, 1979) was constructed for the study area. The simulation model (FEFLOW) used in this modelling study is based on three-dimensional groundwater flow and may be described by the following equation:

$$\frac{\partial}{\partial x}(K_x\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_y\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(K_z\frac{\partial h}{\partial z})\pm W=S\frac{\partial h}{\partial t} \qquad (1)$$

where

h = hydraulic head [L]

K_x,K_y,K_z = Hydraulic Conductivity [L/T]

S = storage coefficient

t = time [T]

W = source (recharge) or sink (pumping) per unit area [L/T]

x,y,z = spatial co-ordinates [L]

6.6 Model Boundary Conditions

Boundary conditions express the way the considered domain interacts with its environment. In other words, they express the conditions of known water flux, or known variables, such as piezometric head. Different boundary conditions result in different solutions hence the importance of stating the correct boundary conditions. Boundary conditions in a groundwater flow model can be specified either as:

- Dirichlet Type (or constant head) boundary conditions or;
- Neuman Type (or specified flux) boundary conditions; and
- or a mixture of the above.

6.6.1 Model Perimeter Boundary Conditions

Groundwater flow directions largely follow topography, and the groundwater basin geometry can be approximated by the surface water drainage geometry. The boundaries of the numerical model are

shown on Figure 6-1. The model area perimeter coincides mostly to surface water divides. The boundaries on surface water divides are represented numerically by what is referred to as a "no-flow" boundary condition (Zero specified flux Neuman Type II boundary condition).

6.6.2 Internal Model Boundaries

The groundwater system within the study area is largely recharged via infiltration of precipitation. It is thought that most of the groundwater recharge occurring within the study area discharges internally to the surface drainage systems via springs and discharge to the base of river drainage systems (base flow) and pans. Constant head boundary conditions were therefore specified along the major surface drainages, which are known to receive base flow from groundwater as, indicated in Figure 6-2. The constant head boundary condition allows groundwater to discharge, in this case, from the model area at a rate dependent on the hydraulic conductivity and hydraulic gradient across the boundary. The constant head boundaries were constrained so that water can only be removed from the system – a reversal of the hydraulic gradient back towards the aquifer from the surface system would therefore not allow water to enter the aquifer from the surface water system. This therefore represents a true "drain type" boundary condition.

6.6.3 Model Base Boundary Condition

The model domain was assumed to extend vertically to a depth of 80m in the hard rock aquifers. It is assumed that the base of the model is impermeable.

6.6.4 Model Surface Boundary Condition

Boundary conditions applied to the top surface area of the model include the following. A defined quantity of background recharge is assigned (5 mm/a) for the steady state simulation (calibration). This constitutes about 1% of MAP for the Karoo aquifers. This is in line with the corresponding hydraulic conductivity values for the different aquifers in the area.

6.7 Hydrogeological Units

The geologic formations of the study area were discussed in Section 3. Figure 3-1 shows the surface expression of the assigned hydrostratigraphic units in the model.

6.8 Hydraulic Stresses

The conceptualized water balance components that are considered were simulated in the numerical model using the available components of the Feflow software package. This included the "Inflow-Outflow from surface" package to simulate natural groundwater recharge and the constant head boundary condition Type I to simulate outflow from the internal model boundaries.

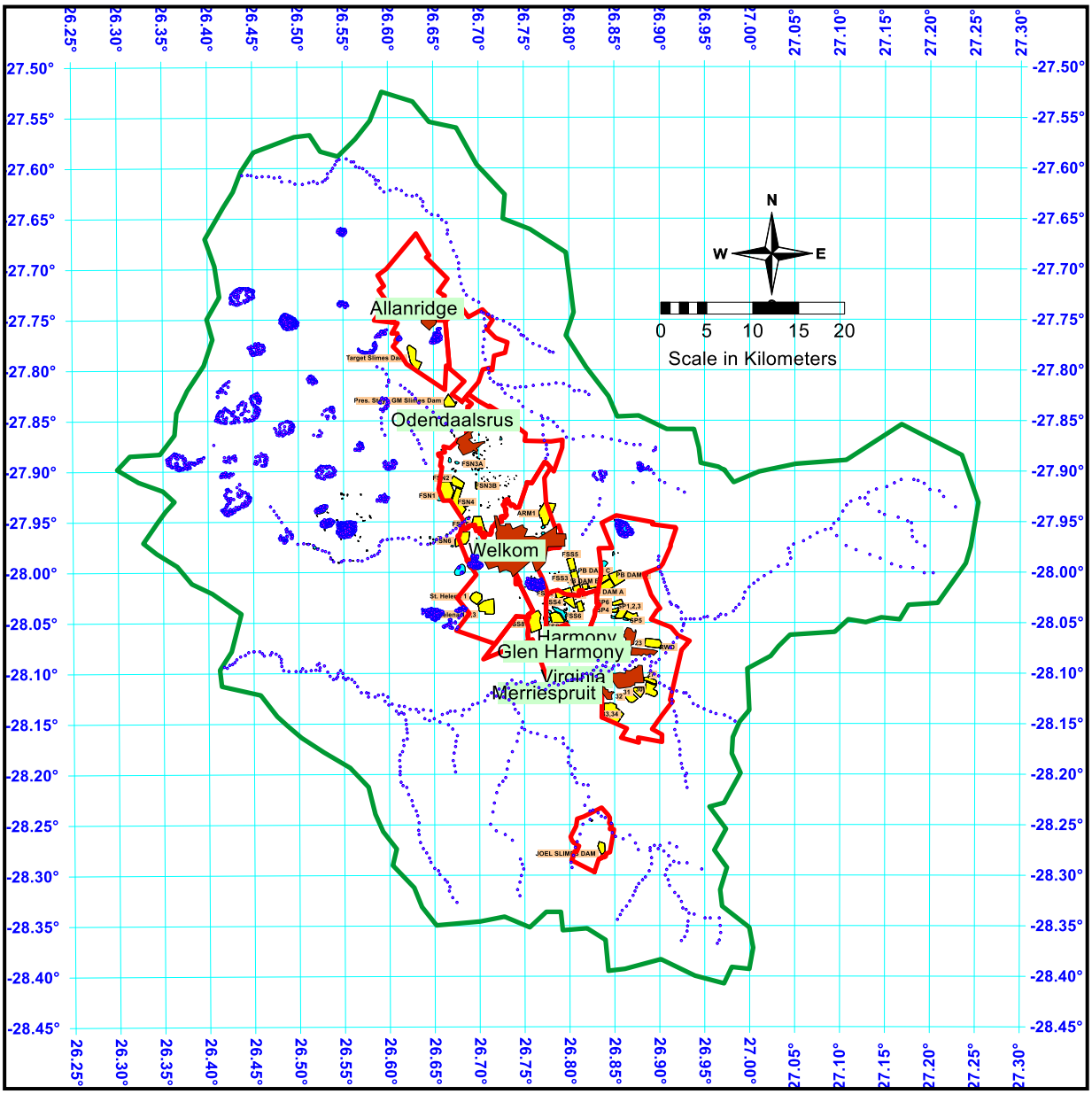


Figure 6-2 Internal Modelling Boundaries (Dark Blue Circles) (Type I Dirichlet) Representing Drain Nodes along Rivers and Streams and on Pans.

6.9 Calibration Approach

Calibration is the process of finding a set of parameters, boundary conditions, and stresses that best reproduce the observed water levels and/or fluxes (Anderson and Woesner, 1992). A standard trial-and-error approach to calibrate the model was used. Theoretically, hydraulic conductivity, hydraulic stresses (such as recharge rates from precipitation and borehole abstraction during transient calibration), and the hydraulic boundary conditions can be modified until the best possible match is made to the observed water level conditions. The water level data shown in Figure 4-11 and Table 4-2 was used for steady state model calibration purposes.

A sensitivity analyses was performed subsequent to the steady state model calibration. A sensitivity analyses is important to quantify the uncertainty in the calibrated model caused by uncertainty in estimates of the model input parameters. As described in Section 7.6 the model results were found to be sensitive to the values of particular model parameters. This uncertainty, therefore, must be taken into account when evaluating the model predictions. Hydraulic conductivity and hydraulic stresses (groundwater recharge) were tested, and the model response was noted. As part of this process, better combinations of parameters were found to result in a better model calibration, and the sensitivity analyses was repeated on the new calibration.

7 Model Construction, Calibration and Sensitivity Analysis

7.1 Model Area and Finite Element Mesh

The numerical model includes all Harmony's Welkom infrastructure namely all the TSF facilities. This necessitated the inclusion of various surface sub-catchments such as the Sand Spruit, the Mahem Spruit, the Sand and Doring Rivers, the Merrie Spruit and Riet Spruit. It extends to cover a very large region over a total area of 4500 square kilometres.

A finite element network (grid) was designed to provide a high resolution of the numerical solution, while at the same time, accommodating the large model area. The finite element grid was compiled using the FEFLOW pre-processing software, which facilitated the construction of 6-noded triangular prism elements over the area of investigation as shown in Figure 7-1. The triangular grid consists of 806888 elements and 607548 nodes substantially larger than the 2017 model (120096 elements and 91578 nodes). The positions of the different geological units and TSF's, RWD's and WRD's are incorporated in the modelling grid as well as the various surface catchments. The model mesh was considerably refined around the drainages and potential sources of contamination for improved numerical accuracy. The model consists of two layers with constant thicknesses of 10 m for the weathered aquifer and 70 m for the fractured rock aquifer for a total model thickness of 80 metres. The elevation of the top slice was set equal to the topographic elevation. A 3D-view of the modelling area is provided in Figure 7-2.

7.2 Model Perimeter and Internal Boundaries

No-flow boundaries were used to represent the hydrologic boundaries for the surface catchments. Constant head boundaries were assigned along the major drainages (Sand Spruit, Mahem Spruit, Sand River, Doring River, Merrie Spruit and Riet Spruit and along major tributaries of these drainages and some of major pans to represent outflow boundaries. Thus, all groundwater within the study area was assumed to originate as spatially distributed recharge within the model domain. It is thought that most of the groundwater recharge occurring within the study area discharges internally to the surface drainage systems via springs and discharge to the base of river drainage systems (baseflow) and to pans.

7.3 Upper Model Boundary

The topography was used to specify the upper modelling boundary in the model. FEFLOW's "inflow/outflow on top slice" condition was used to define recharge in Slice 1 (top of Layer 1) in the model.

7.4 Model Properties

7.4.1 Hydraulic Conductivity and Transmissivity

The major hydrogeological units in the study area are described in previous sections of the report. The hydraulic conductivities of these units were assigned to the model based on the estimated hydraulic properties obtained from pumping tests conducted to date and first model calibration and sensitivity runs. Estimates of the hydraulic conductivity and transmissivity were obtained from the results of constant rate discharge tests. Figure 4-18 and Table 4-5 and Table 4-4 show the results of

the pumping tests conducted in the hard rock aquifers across the Harmony Welkom Study Area.

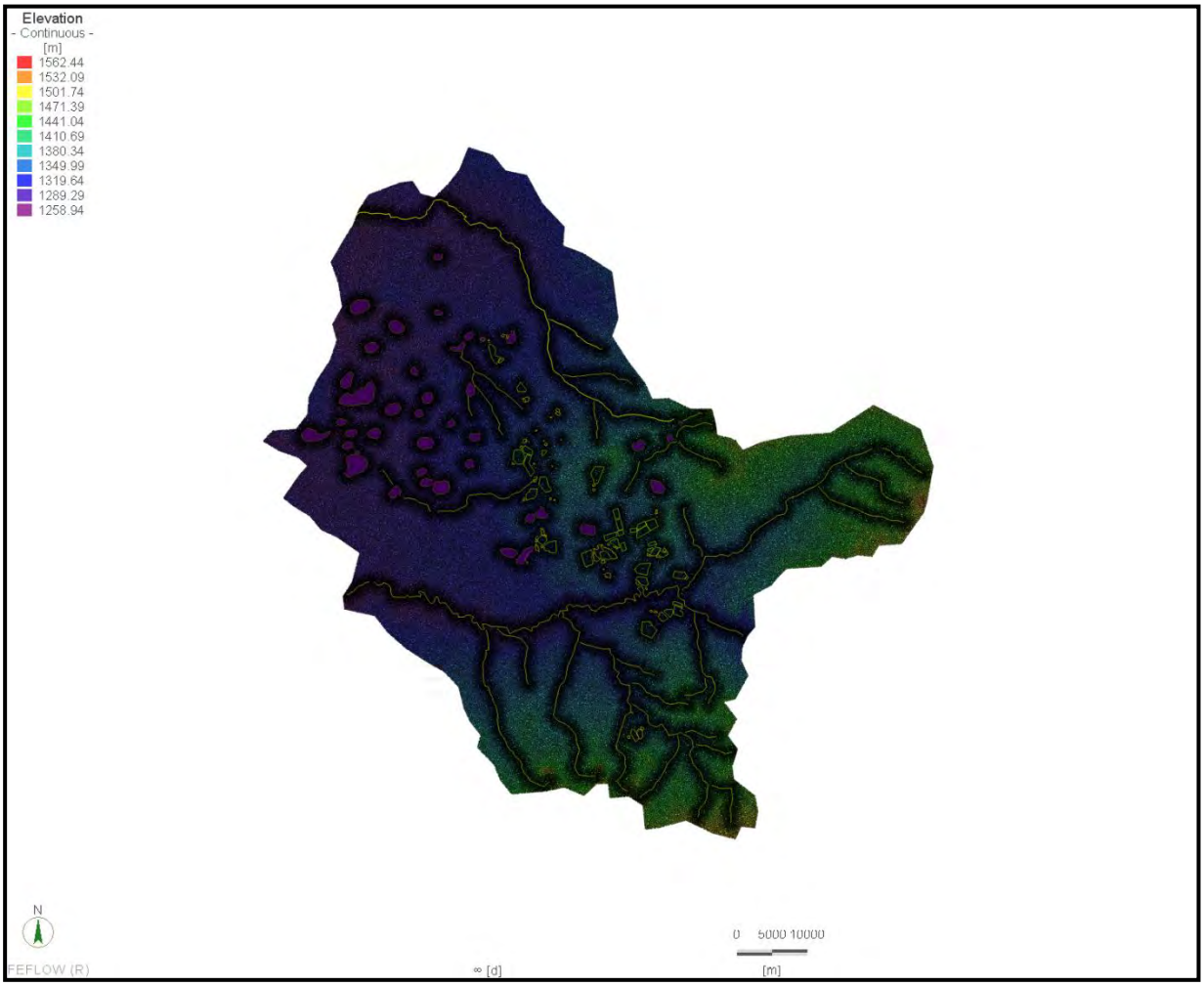


Figure 7-1 Finite Element Mesh.

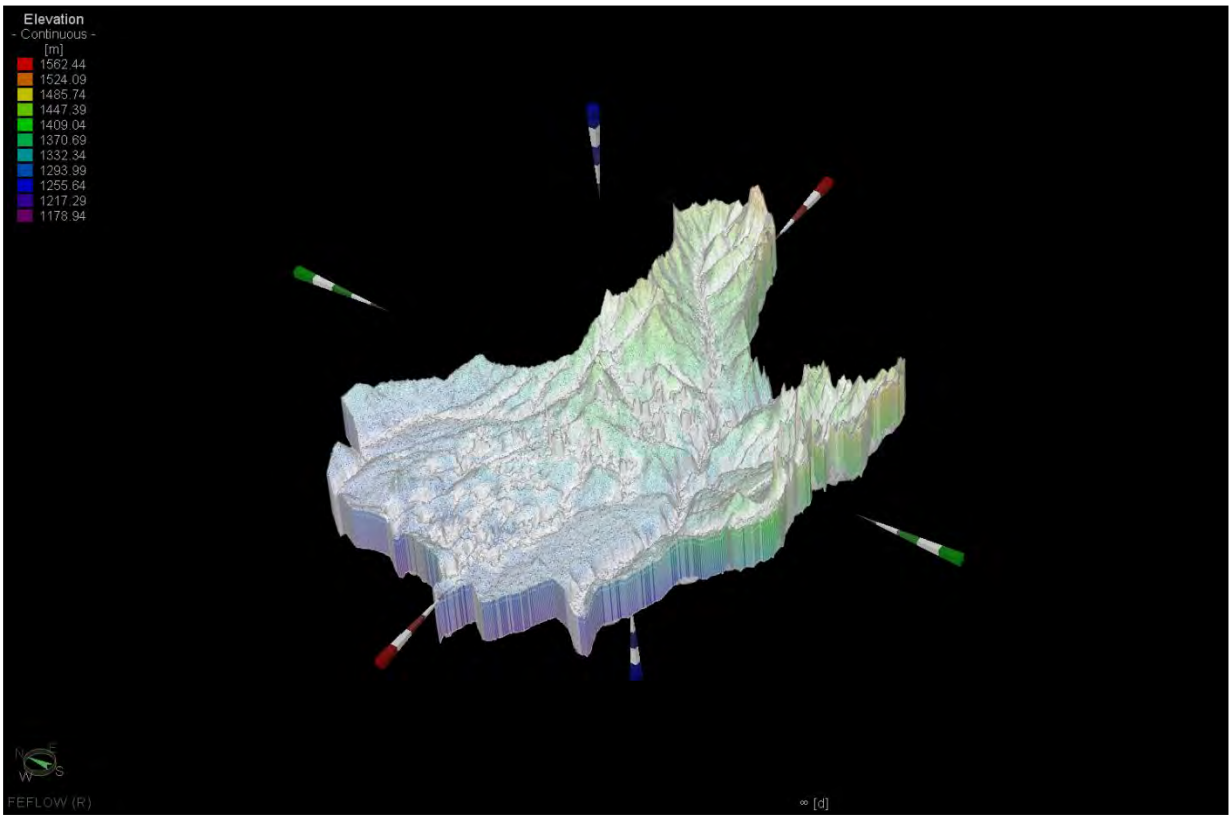


Figure 7-2 Three-Dimensional View of the Finite Element Network.

7.4.2 Storativity

For the steady-state model, storativity is not required. For transient state simulations a specific storage value of $1x10^{-4}$/m was used for the hard rock aquifers – this would provide an equivalent aquifer storage coefficient of 0.006 or 0.6 percent, which is representative for these hard rock aquifer conditions.

7.4.3 Recharge

The annual recharge is estimated to be in the order of 1% of MAP across the Karoo aquifers.

7.4.4 Evaporation

Evapotranspiration was not specified in the model. It is assumed that the (effective) recharge specified in the model has already overcome the effect of evapotranspiration losses from the system.

7.4.5 Initial Head Conditions

The initial head conditions specified in the model were interpolated from the measured groundwater levels using the Kriging technique and extrapolated to the nodes in the model.

7.5 Steady State Calibration

7.5.1 Steady State Flow Equation

For steady state conditions the groundwater flow equation (1) reduces to the following equation:

$$\frac{\partial}{\partial x}(K_x\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_y\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(K_z\frac{\partial h}{\partial z})\pm W=0 \qquad (2)$$

According to the conceptual model for the system the calculated head distribution (hx, hy, hz) is dependent upon the recharge from rainfall, hydraulic conductivity and boundary conditions. For a given hydraulic conductivity value (or transmissivity value) and set of boundary conditions specified, the head distribution across the aquifer can be obtained for a specific recharge value. This simulated head distribution can then be compared to the measured head distribution and the effective recharge values can be altered until an acceptable correspondence between measured and simulated heads is obtained.

7.5.2 Steady State Calibration Approach

Steady state calibration was accomplished by varying the hydraulic conductivity values and keeping the recharge rate constant, until a reasonable match between the measured groundwater elevations and the simulated groundwater elevations was obtained. A constant recharge was used because localized recharge variations (based on slope or soil type) cannot be determined with the limited data available at this time. For the purpose of this modelling study, a constant recharge rate is considered reasonable and likely to result in similar regional predictions compared to spatially distributed recharge. The model was calibrated using groundwater levels that could be obtained from the desk study phase of this investigation excluding water levels which could be identified as outlier values. Figure 7-3 shows the locations of target boreholes used for calibration purposes.

7.5.3 Simulation of Water Levels for State Conditions

Figure 7-4 shows the simulated steady state groundwater elevations and groundwater flow directions for the steady state calibration. There are insufficient boreholes with groundwater level data to create an observed water table map for the entire model area. Therefore, the model output has been evaluated in a qualitative manner by observing the shape of the water table contours near known hydraulic boundaries, divides and drainages. The calibrated model water table is like what would be expected at the location of internal watersheds divides and major drainages. As shown on Figure 7-4, the water table closely conforms to local topographic features.

American Society for Testing and Materials (ASTM) guidelines, as well as widely accepted methods presented in Anderson and Woessner (1992) and Spitz and Moreno (1996) were followed for calibration of the model. The difference between the simulated and the observed hydraulic head (residual) was calculated for each target (Table 7-1). The error in the calibration was expressed by three common methods: the mean error (ME), the mean absolute error (MAE) and the root mean squared (RMS) error (Anderson and Woessner 1992).

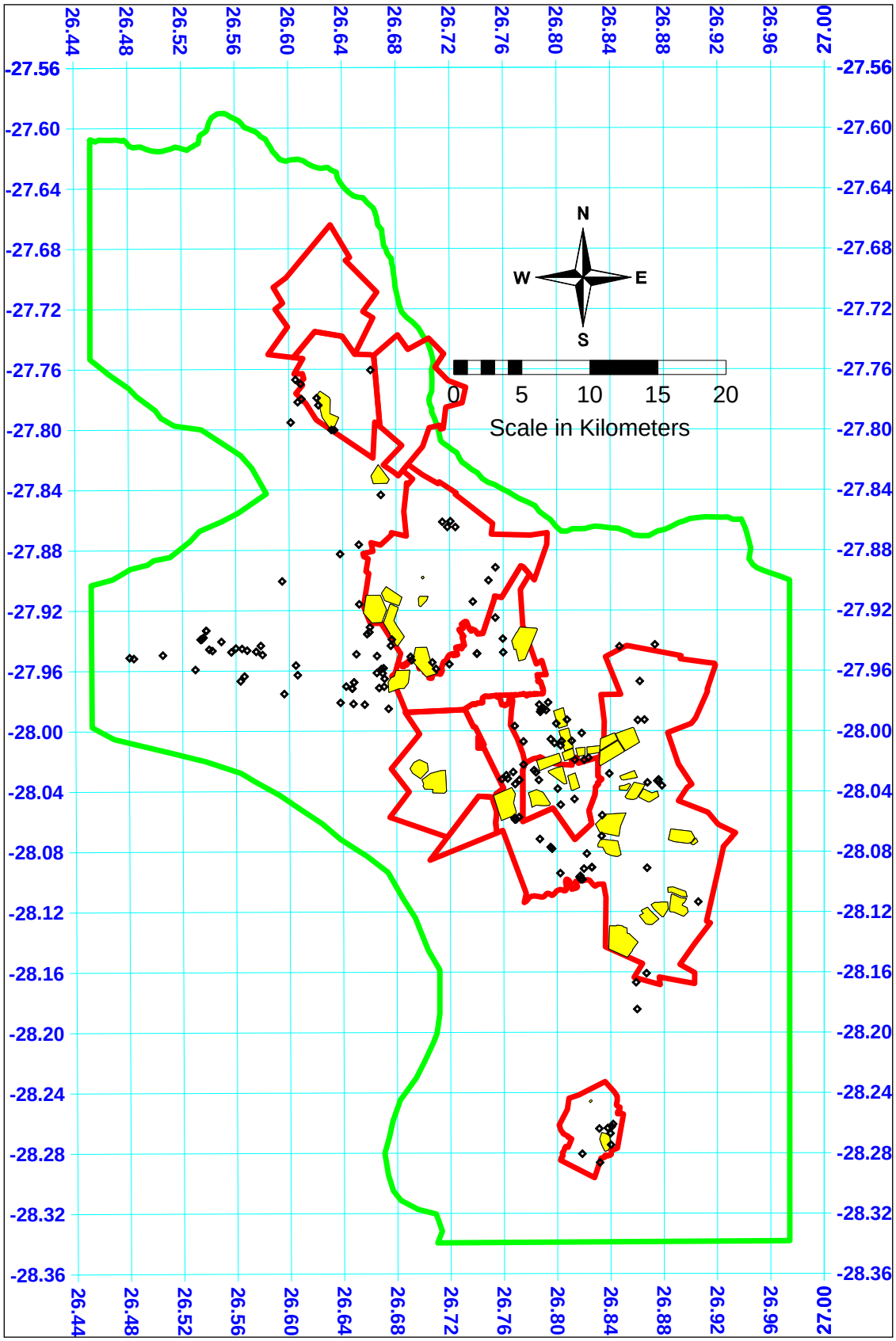


Figure 7-3 Positions of Boreholes (indicated by the black diamonds) used for Steady State Calibrations Purposes.

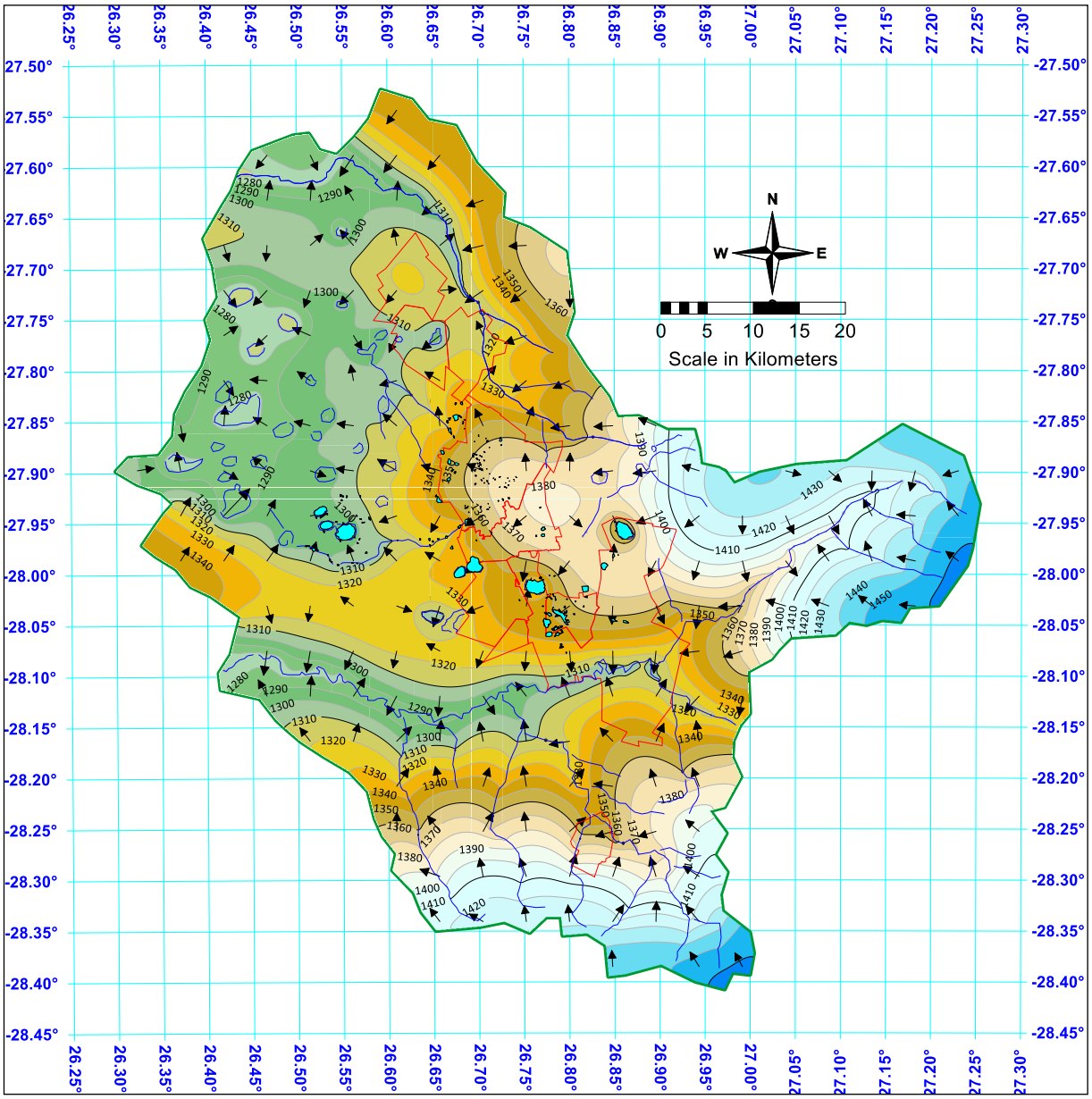


Figure 7-4 Simulated Steady State Water Levels and Groundwater Flow Directions.

The ME is the mean difference between measured (WLm) and simulated (WLs) water levels:

$$ME = 1/n \Sigma(WLm- WLs)i, \text{ for } i=1 \text{ to } n, \text{ the number of calibration targets.}$$

A small ME is not necessarily an indication of a good calibration, because negative and positive residuals, even if large, can cancel each other out, resulting in a small ME. The MAE addresses this as the mean of the absolute value of the differences in measured and simulated water levels:

$$MAE = 1/n \Sigma |(WLm- WLs)i|.$$

The RMS error is the average of the squared differences in measured and simulated water levels.

$$RMS = [1/n \Sigma(WLm- WLs)i^2]0.5.$$

In keeping with standard practice, the RMS error was evaluated as a ratio to the total water level

change across the model domain. If the ratio is small, the errors are only a small part of the overall model response (Anderson and Woessner 1992). The ME, MAE, and RMS error were calculated using all the calibration targets for the available data set. The Mean Error for the data set is − 4.58 metres. The Mean Absolute Error for the data set is 7.82 metres. The Root Mean Squared error is 9.93 metres and 8.2 percent of the range of water level change across the model domain (see Table 7-1).

The observed groundwater levels were plotted against the simulated water levels in a scatter plot for the data set (Figure 7-5) and in a line-graph (Figure 7-6). Deviations from the straight line indicating a perfect match between the observed and simulated values should be randomly distributed indicating that there is no bias toward over or under predicting the groundwater levels (Anderson and Woessner 1992). A correlation coefficient of 95% was obtained between the simulated and observed groundwater elevations for the data set. The plot of the modelling errors for the data set (Figure 7-7) indicates that the model is generally not under or over-predicting the groundwater elevations.

7.5.4 Calibrated Hydraulic Conductivity and Transmissivity

The hydraulic conductivity and transmissivity for the different geological layers and zones for the calibrated model are summarized in Table 7-2.

7.6 Model Sensitivity Analysis

The model has been calibrated by assuming a constant recharge value across the modelling domain and altering hydraulic conductivity until a reasonable resemblance was obtained between observed and simulated water levels. The following sections will provide an indication of the sensitivity of the model to the hydraulic conductivity (K) and recharge (Re).

7.6.1 Sensitivity of the Model to K-values

In order to demonstrate the sensitivity of the model to hydraulic conductivity this parameter was adjusted to double the calibrated values (higher) and half the calibrated value (lower). The effect of these changes is depicted in Figure 7-8. An increase in the K-value increases the RMS of the calibration from 8.28% to 9.4% whilst a decrease in the K-value increases the RMS of the calibration from 8.28% to 19.6%.

Table 7-1 Steady State Calibration Measures for Steady State Model.

Borehole	Observed SWL (mamsl)	Simulated Water Level (mamsl)	ME (m)	MAE (m)	RMS (m)
			(WLm- WLs)i	|(WLm- WLs)i|	(WLm- WLs)i2
A1	1302.18	1302.43	-0.25	0.25	0.06
A2	1312.30	1308.81	3.49	3.49	12.18
A3	1314.13	1310.14	3.99	3.99	15.94
A4	1312.74	1315.54	-2.80	2.80	7.81
A5	1312.37	1316.19	-3.82	3.82	14.61
B2N1	1303.93	1305.21	-1.28	1.28	1.63
B2N2	1302.72	1304.50	-1.78	1.78	3.18
B38N	1301.91	1301.59	0.32	0.32	0.10
B41S	1297.75	1304.35	-6.60	6.60	43.59
BH01	1350.35	1364.80	-14.45	14.45	208.91
BH02	1357.16	1365.81	-8.65	8.65	74.76

Borehole	Observed SWL (mamsl)	Simulated Water Level (mamsl)	ME (m)	MAE (m)	RMS (m)
			(WLm- WLs)i	|(WLm- WLs)i|	(WLm- WLs)i2
BH03	1308.57	1312.41	-3.84	3.84	14.73
BH04	1326.29	1329.86	-3.57	3.57	12.76
BH05	1324.93	1330.89	-5.96	5.96	35.57
BH06	1335.48	1335.53	-0.05	0.05	0.00
BH08	1339.58	1343.13	-3.55	3.55	12.59
BH10	1345.03	1341.86	3.17	3.17	10.03
BH100	1293.12	1294.45	-1.33	1.33	1.76
BH101	1294.62	1294.37	0.25	0.25	0.06
BH102	1295.97	1294.06	1.91	1.91	3.63
BH103	1294.55	1293.89	0.66	0.66	0.43
BH104	1295.09	1295.00	0.09	0.09	0.01
BH10HDP1	1320.90	1321.81	-0.91	0.91	0.82
BH11	1355.41	1367.46	-12.05	12.05	145.31
BH113	1310.41	1332.18	-21.77	21.77	473.94
BH114	1290.74	1295.35	-4.61	4.61	21.22
BH115	1292.49	1294.56	-2.07	2.07	4.27
BH117	1302.24	1297.11	5.13	5.13	26.35
BH118	1299.79	1298.44	1.35	1.35	1.83
BH119	1293.66	1299.13	-5.47	5.47	29.89
BH12	1341.35	1342.35	-1.00	1.00	1.00
BH120	1355.21	1368.76	-13.55	13.55	183.71
BH121	1357.99	1371.43	-13.44	13.44	180.64
BH122	1341.22	1351.17	-9.95	9.95	99.08
BH123	1346.23	1354.63	-8.40	8.40	70.60
BH124	1307.74	1300.90	6.84	6.84	46.78
BH125	1297.54	1297.11	0.43	0.43	0.19
BH126	1297.91	1295.43	2.48	2.48	6.15
BH128	1293.90	1296.84	-2.94	2.94	8.62
BH129	1372.35	1380.71	-8.36	8.36	69.82
BH13	1342.62	1342.14	0.48	0.48	0.23
BH131	1354.07	1377.28	-23.21	23.21	538.60
BH133	1375.53	1372.66	2.87	2.87	8.25
BH134	1360.94	1375.93	-14.99	14.99	224.70
BH135	1388.32	1380.76	7.56	7.56	57.23
BH136	1295.04	1331.31	-36.27	36.27	1315.15
BH137	1325.18	1331.66	-6.48	6.48	41.93
BH138	1323.10	1329.22	-6.12	6.12	37.43
BH139	1322.94	1329.54	-6.60	6.60	43.59
BH14	1345.42	1352.08	-6.66	6.66	44.40
BH140	1322.21	1328.61	-6.40	6.40	41.01
BH141	1306.35	1320.72	-14.37	14.37	206.44
BH142	1325.64	1336.15	-10.51	10.51	110.55
BH143	1331.16	1343.89	-12.73	12.73	162.02
BH144	1319.01	1345.12	-26.11	26.11	681.84

Borehole	Observed SWL (mamsl)	Simulated Water Level (mamsl)	ME (m)	MAE (m)	RMS (m)
			(WLm- WLs)i	|(WLm- WLs)i|	(WLm- WLs)i2
BH145	1316.46	1324.87	-8.41	8.41	70.81
BH146	1313.67	1323.11	-9.44	9.44	89.19
BH147	1317.04	1322.15	-5.11	5.11	26.06
BH148	1318.55	1322.15	-3.60	3.60	12.93
BH15	1346.02	1350.86	-4.84	4.84	23.43
BH152	1305.51	1323.05	-17.54	17.54	307.77
BH156	1325.46	1330.01	-4.55	4.55	20.70
BH16	1359.12	1367.61	-8.49	8.49	72.14
BH162	1303.67	1312.63	-8.96	8.96	80.32
BH163	1304.84	1315.47	-10.63	10.63	112.99
BH17	1361.19	1368.64	-7.45	7.45	55.52
BH170	1327.27	1330.92	-3.65	3.65	13.31
BH176	1309.45	1314.66	-5.21	5.21	27.18
BH177	1325.12	1337.51	-12.39	12.39	153.58
BH18	1363.49	1369.91	-6.42	6.42	41.16
BH182	1343.80	1350.14	-6.34	6.34	40.20
BH183	1343.89	1351.08	-7.19	7.19	51.77
BH184	1345.09	1346.19	-1.10	1.10	1.22
BH185	1344.59	1345.90	-1.31	1.31	1.72
BH186	1345.39	1343.23	2.16	2.16	4.67
BH187	1347.67	1343.37	4.30	4.30	18.47
BH188	1347.53	1343.72	3.81	3.81	14.52
BH189	1346.60	1342.51	4.09	4.09	16.76
BH19	1364.59	1371.98	-7.39	7.39	54.63
BH190	1361.38	1368.40	-7.02	7.02	49.28
BH193	1374.96	1365.21	9.75	9.75	95.07
BH195	1344.34	1358.93	-14.59	14.59	212.85
BH196	1337.46	1359.49	-22.03	22.03	485.54
BH197	1340.21	1357.20	-16.99	16.99	288.62
BH198	1333.59	1356.77	-23.18	23.18	537.08
BH199	1348.65	1342.60	6.05	6.05	36.58
BH1H	1348.57	1348.06	0.51	0.51	0.26
BH20	1359.04	1369.52	-10.48	10.48	109.74
BH208	1308.10	1315.10	-7.00	7.00	48.96
BH209	1301.93	1309.51	-7.58	7.58	57.43
BH20H	1299.14	1307.34	-8.20	8.20	67.26
BH21	1356.80	1369.53	-12.73	12.73	162.16
BH210	1366.72	1364.19	2.53	2.53	6.40
BH211	1335.05	1345.56	-10.51	10.51	110.51
BH212	1357.91	1357.56	0.35	0.35	0.12
BH213	1353.77	1357.47	-3.70	3.70	13.70
BH215	1351.21	1355.78	-4.57	4.57	20.91
BH22	1352.59	1366.02	-13.43	13.43	180.27
BH23	1353.41	1363.06	-9.65	9.65	93.04

Borehole	Observed SWL (mamsl)	Simulated Water Level (mamsl)	ME (m)	MAE (m)	RMS (m)
			(WLm- WLs)i	|(WLm- WLs)i|	(WLm- WLs)i2
BH24	1378.97	1360.93	18.04	18.04	325.51
BH25	1383.83	1363.75	20.08	20.08	403.38
BH25H	1298.51	1313.35	-14.84	14.84	220.35
BH27	1368.72	1366.49	2.23	2.23	4.98
BH28	1381.04	1363.28	17.76	17.76	315.25
BH29	1384.91	1375.95	8.96	8.96	80.29
BH2H	1334.37	1334.32	0.05	0.05	0.00
BH30	1344.90	1342.52	2.38	2.38	5.65
BH31	1348.08	1355.49	-7.41	7.41	54.96
BH32	1361.17	1367.73	-6.56	6.56	43.07
BH33	1361.29	1368.61	-7.32	7.32	53.59
BH35	1369.10	1375.43	-6.33	6.33	40.07
BH36	1357.47	1371.84	-14.37	14.37	206.48
BH37	1376.36	1379.16	-2.80	2.80	7.85
BH38	1378.83	1374.56	4.27	4.27	18.23
BH39	1380.89	1374.47	6.42	6.42	41.24
BH40	1330.21	1342.69	-12.48	12.48	155.81
BH41	1332.13	1345.30	-13.17	13.17	173.35
BH42	1335.04	1345.01	-9.97	9.97	99.36
BH43	1329.89	1346.18	-16.29	16.29	265.41
BH44	1351.84	1362.48	-10.64	10.64	113.13
BH45	1327.27	1342.82	-15.55	15.55	241.90
BH46	1324.58	1329.69	-5.11	5.11	26.14
BH47	1323.91	1334.18	-10.27	10.27	105.54
BH48	1324.16	1327.45	-3.29	3.29	10.84
BH51	1293.72	1294.50	-0.78	0.78	0.61
BH52	1277.80	1294.75	-16.95	16.95	287.17
BH55	1331.36	1334.29	-2.93	2.93	8.61
BH59	1311.56	1306.43	5.13	5.13	26.29
BH60	1314.10	1310.82	3.28	3.28	10.73
BH61	1311.67	1309.11	2.56	2.56	6.57
BH63	1389.29	1375.39	13.90	13.90	193.11
BH65	1309.52	1305.80	3.72	3.72	13.87
BH66	1306.84	1309.20	-2.36	2.36	5.56
BH68	1293.10	1303.78	-10.68	10.68	114.17
BH69	1295.48	1303.32	-7.84	7.84	61.53
BH70	1330.40	1332.75	-2.35	2.35	5.52
BH72	1310.39	1332.28	-21.89	21.89	479.31
BH73	1298.30	1308.26	-9.96	9.96	99.11
BH74	1293.14	1306.34	-13.20	13.20	174.19
BH75	1307.30	1309.00	-1.70	1.70	2.89
BH76	1292.04	1300.82	-8.78	8.78	77.15
BH77	1292.65	1298.72	-6.07	6.07	36.81
BH78	1297.64	1298.83	-1.19	1.19	1.41

Borehole	Observed SWL (mamsl)	Simulated Water Level (mamsl)	ME (m)	MAE (m)	RMS (m)
			(WLm- WLs)i	|(WLm- WLs)i|	(WLm- WLs)i2
BH89H	1356.38	1352.15	4.23	4.23	17.93
BH91H	1364.16	1350.71	13.45	13.45	180.78
BH93H	1381.00	1358.62	22.38	22.38	500.69
BH96	1293.64	1302.59	-8.95	8.95	80.14
J1	1359.03	1370.41	-11.38	11.38	129.50
J11	1344.85	1364.92	-20.07	20.07	402.81
J2	1346.57	1362.69	-16.12	16.12	259.84
J5	1385.15	1392.16	-7.01	7.01	49.17
KLM1	1397.70	1387.18	10.52	10.52	110.74
KLM2	1370.78	1368.77	2.01	2.01	4.03
KLM3	1357.68	1367.05	-9.37	9.37	87.82
KLM4	1369.34	1378.95	-9.61	9.61	92.33
P5	1358.84	1347.27	11.57	11.57	133.96
P7	1356.37	1348.03	8.34	8.34	69.49
STHH2	1329.72	1335.01	-5.29	5.29	27.97
STHH3	1335.36	1337.70	-2.34	2.34	5.45
STHH4	1343.44	1337.70	5.74	5.74	32.89
STHM2	1325.23	1332.43	-7.20	7.20	51.78
STHM3	1325.02	1332.39	-7.37	7.37	54.34
STHM4	1320.09	1324.38	-4.29	4.29	18.42
VP2	1308.54	1304.18	4.36	4.36	18.97
			Σ = -750.74	Σ = 1282.64	Σ = 16190.84
			1/n = -4.58	1/n = 7.82	1/n = 98.72
					SQRT = 9.93
					RMS% of water level range = 0.0828

7.6.2 Sensitivity of the Model to Recharge

In order to demonstrate the sensitivity of the model to recharge this parameter was adjusted double the calibrated values (higher) and half the calibrated value (lower). The effect of these changes is depicted in Figure 7-9. An increase in the Re-value increases the RMS of the calibration from 8.28% to 19.6% whilst a decrease in the Re-value increases the RMS of the calibration from 8.28% to 9.4%.

The interdependence of the K-value and recharge is clearly demonstrated with the sensitivity analysis and further illustrates the non-uniqueness of the solution of the groundwater flow equation. As a result of the interdependence of these two parameters it is clear that an increase in recharge has the same effect as a corresponding decrease in the K-value.

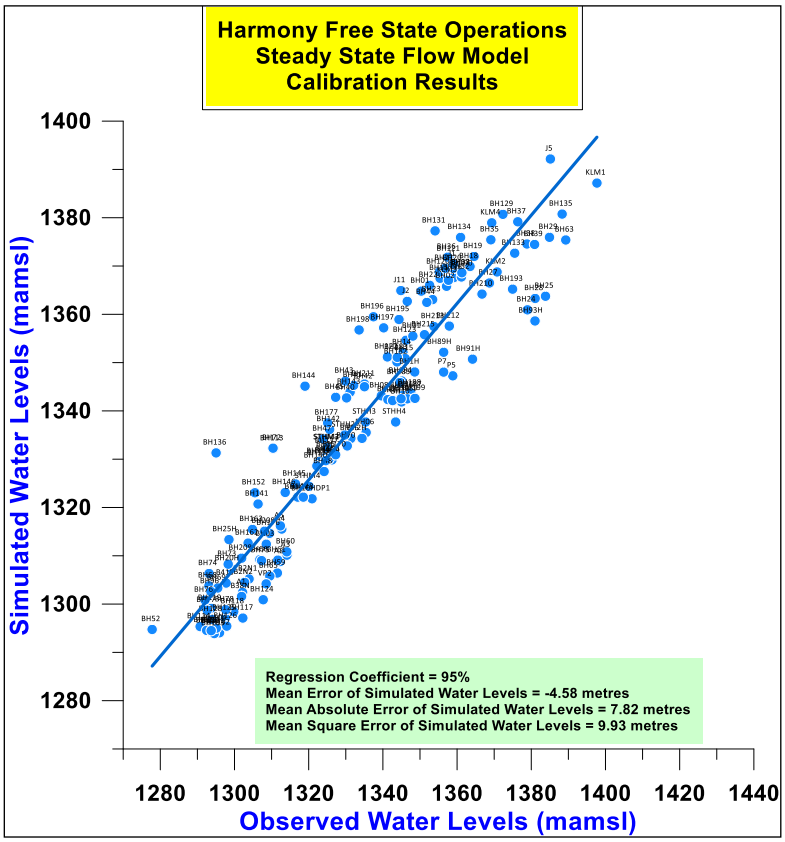


Figure 7-5 Scatter Plot of Simulated Versus Observed Groundwater Levels.

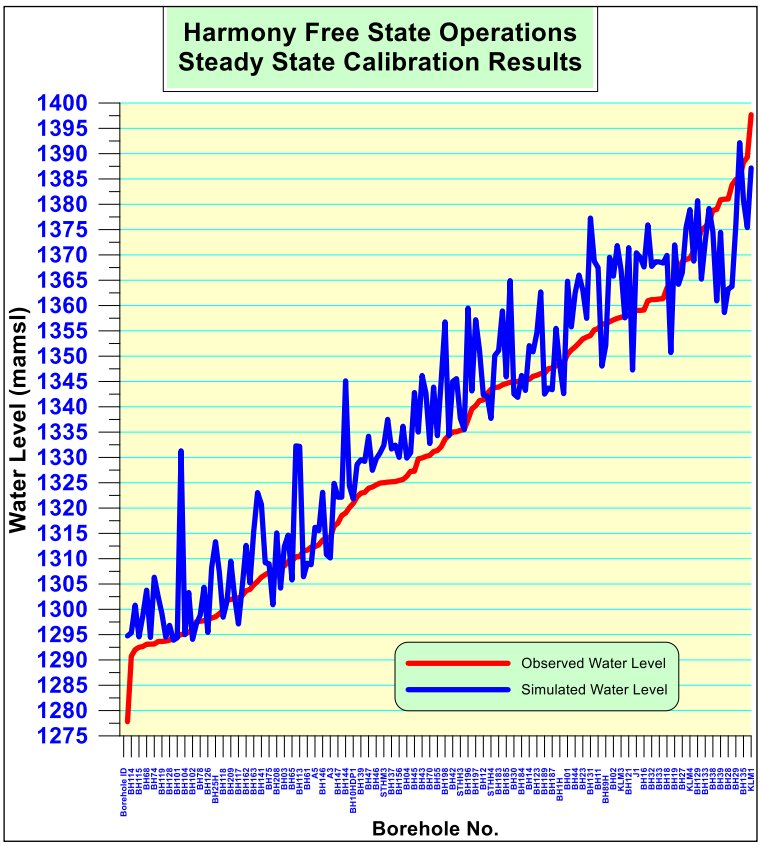


Figure 7-6 Line Plot of Simulated Versus Observed Groundwater Levels.

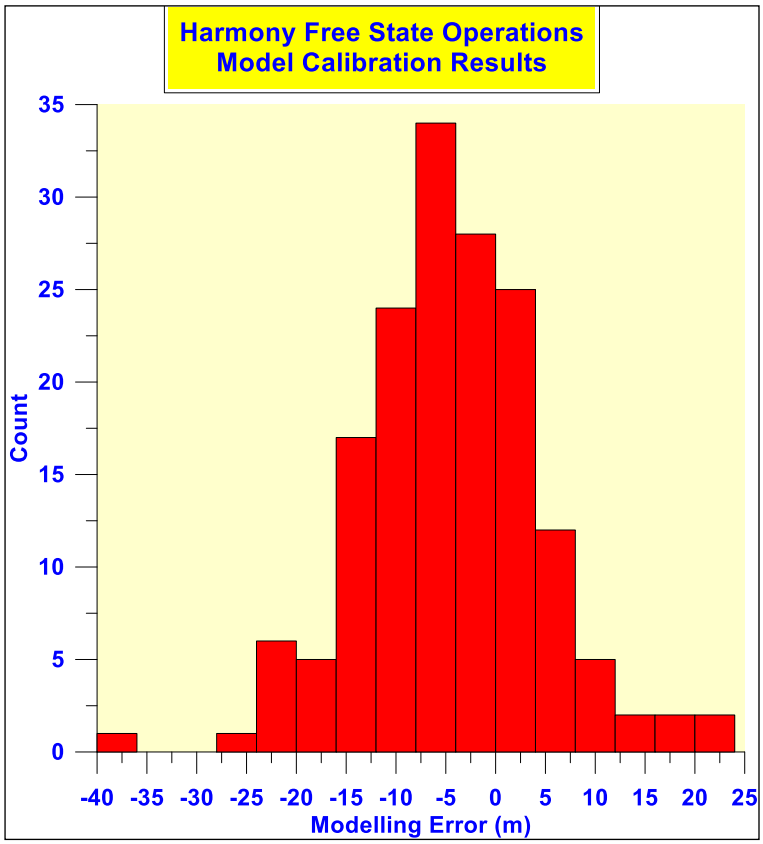


Figure 7-7 Frequency Distribution of Modelling Errors.

Table 7-2 Calibrated Hydraulic Conductivity and Transmissivity.

Layer	Thickness m	K-value m/s	K-value m/d	T-value m^2/d
1	10	1.37E-06	1.1184E-01	1.184E+00
2	70	3.24E-07	2.8E-02	1.960E+00

7.7 Conclusions of Model Calibration

The following is concluded from the groundwater flow calibrations:

- The hydraulic conductivity zoning used corresponds with the nature and distribution of the geological units and control the hydrogeology of the study area. The zoning mimics the primary geological features across the regional study area. The large-scale, effective hydraulic conductivity values identified in the model calibration compare well with the hydraulic conductivity (transmissivity) data from the tests conducted by Golder (2008) (see Figure 7-10) and what is widely accepted values for this type of formations/aquifers.
- The background recharge values used in the model is consistent with estimates for hard rock- and dolomite type aquifers.
- The steady state water balance for the modelled area indicates groundwater outflow from the total modelled area in the order of 22502 m^3/d into the drainages. This is balanced by recharge. No flow measurements to verify this result are available.

- Overall, the model structure and parameters used in the calibrated model appear appropriate and reasonable for the planned use. The model-calculated hydraulic heads are consistent with the target heads, and the overall shape of the water table is consistent with that expected and discussed in the conceptual model. The model shows groundwater recharge occurring and discharging within the surface drainages consistent with the conceptual model.
- The model should form part of the long-term monitoring and assessment for the Harmony Free State Gold Mines Properties.

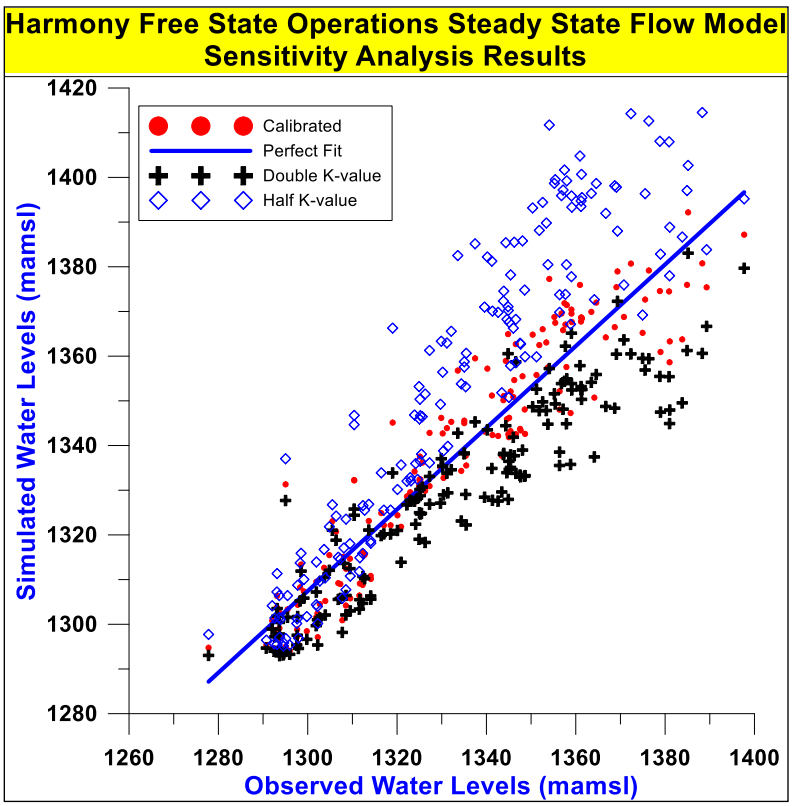


Figure 7-8 Sensitivity of Model to K-values (K-values Double the Calibrated Values).

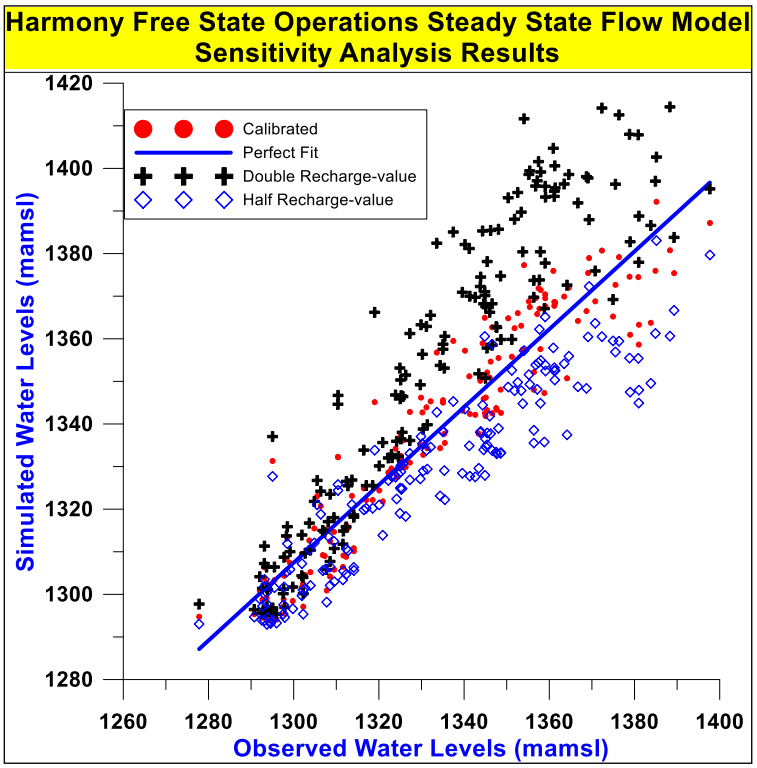


Figure 7-9 Sensitivity of Model to Recharge-values (Recharge-values Half the Calibrated Values).

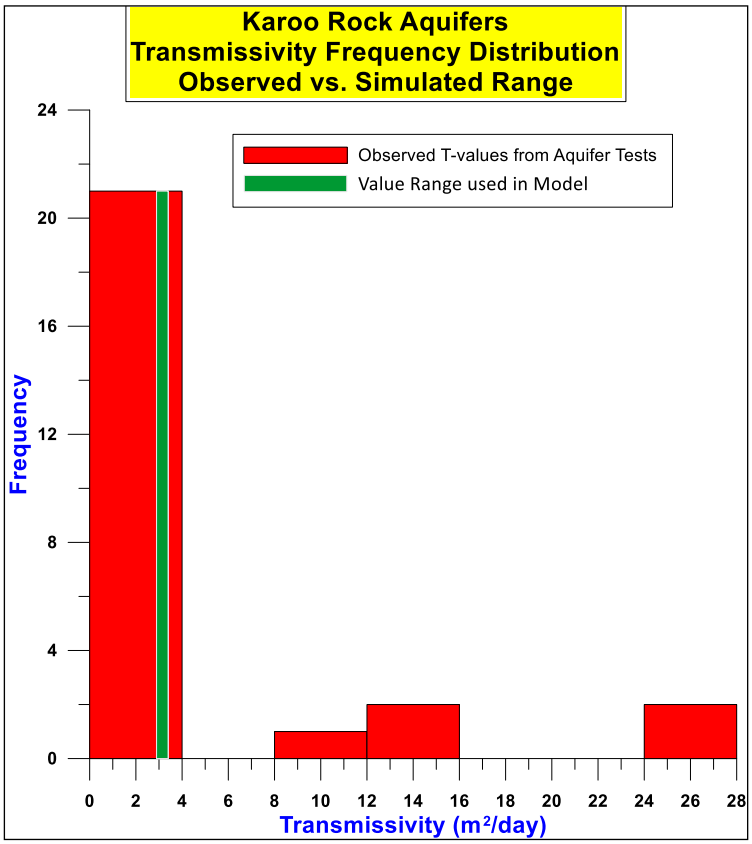


Figure 7-10 Range of Observed T-values vs. Range of Calibrated T-values used in the Model for the Hard Rock Aquifers.



8 Mass Transport Model Development

8.1 Introduction

One of the main objectives of this study is the development of a preliminary mass transport model for Harmony's Tailings Storage Facilities (TSF), Return Water Dams (RWD), Waste Rock Dumps (WRD), Process Water Dams and other sources of interest in order to assess impacts from these sources on groundwater and other receptors of interest within their operations.

The frequent discoveries of groundwater contamination highlight the need to understand the transport behaviour of contaminants. A groundwater contamination plume generally contains numerous contaminants. Each contaminant within the plume may migrate differently, and some will react with each other. In transport predictions, one normally concentrates on the contaminant that is considered the most significant for the investigated transport problem. For the purposes of this study, the migration of sulphate (SO_4) is investigated, as this is a typical ion associated with goldmine contamination. Numerous gold mines are operational in the study area.

The processes controlling contaminant migration in groundwater is briefly discussed in the following sections.

8.2 Processes Controlling Contaminant Transport Migration

Transport through a porous medium is mainly controlled by the following two processes:

- Advection and
- hydrodynamic dispersion.

For clarity these processes will be discussed briefly.

8.2.1 Advection

Advection is the component of contaminant movement described by Darcy's Law. If uniform flow at a velocity V takes place in the aquifer, Darcy's law calculates the distance (x) over which a labelled water particle migrates over a time period t as $x = Vt$.

8.2.2 Hydrodynamic Dispersion

Hydrodynamic dispersion comprises two processes:

- mechanical dispersion and
- molecular diffusion.

Mechanical dispersion is the process whereby the initially close group of labelled particles is spread in a longitudinal as well as in a transverse direction. This is caused by the velocity distribution (as a result of varying microscopic streamlines) that develops at the microscopic level of flow around the grain particles of the porous medium. Although this spreading is both in the longitudinal and transversal direction of flow, it is primarily in the former direction. Very little spreading can be caused in the transversal direction by velocity variations alone.

Molecular diffusion mainly causes transversal spreading, by the random movement of the molecules in the fluid from higher contaminant concentrations to lower ones. It is thus clear that if $V = 0$, the

contaminant is transported by molecular diffusion only or in other words the higher the velocity of the groundwater the less the relative effect of molecular diffusion on the transportation of a labelled particle.

In addition to advection, mechanical dispersion and molecular diffusion, several other phenomena may affect the concentration distribution of a contaminant as it moves through a porous medium. The contaminant may interact with the solid surface of the porous matrix in the form of adsorption of contaminant particles on the solid surface, deposition, solution of the solid matrix and ion exchange. All these phenomena cause changes in the concentration of a contaminant in a flowing fluid.

8.3 Mass Balance Equation

The mass balance equation (Bear and Verruijt, 1992) (equation of *hydrodynamic dispersion* or the *advection-dispersion* equation) of a pollutant (contaminant) is expressed as:

$$\frac{\delta nc}{\delta t} = -\Delta \bullet q_{c,total} - f + n\rho\Gamma - P_c + R_c \qquad (3)$$

where:

nc = mass of pollutant per unit volume of porous medium.

n = porosity of saturated zone.

c = concentration of pollutant (mass of pollutant per unit volume of liquid (water)).

$\Delta \bullet q_{c,total}$ = excess of inflow of a considered pollutant over outflow, per unit volume of porous medium, per unit time.

f = quantity of pollutant leaving the water (through adsorption, ion exchange etc.);

$n\rho\Gamma$ = mass of pollutant added to the water (or leaving it) as a result of chemical interactions among species inside the water, or by various decay phenomena.

Γ = rate at which the mass of a pollutant is added to the water per unit mass of fluid.

p = density of pollutant.

P_c = total quantity of pollutant withdrawn (pumped) per unit volume of porous medium per unit time.

R_c = total quantity of pollutant added (artificial recharge) per unit volume of porous medium per unit time.

In the case of this investigation, it is assumed that no decay or retardation of contaminants is taking place in the aquifer. The effect of retardation will be reduced due to the fractured flow characteristics of the hard rock formations. Contaminant migration is therefore attributable only to advection and hydrodynamic dispersion. This will provide a worst-case scenario in terms of travel distance of contaminants.

8.4 Numerical Mass Transport Model – Data Input

8.4.1 General

The FEFLOW software was used to approximate the advection and dispersion equation and to provide numerical solutions for the concentration values in the aquifer in time and space. Input required in the software is:

- input concentrations of contaminants.
- hydraulic conductivities in the x- and y- directions.
- porosity values for the saturated portion of the aquifer.
- longitudinal dispersivities.
- transversal dispersivities.
- hydraulic heads in the aquifer over time.

8.4.2 Input Sources and Concentration of Contaminants

In the case of the Harmony Free State Operations, the source terms are defined by the Tailings Storage Facilities (TSF), Return Water Dams (RWD), Waste Rock Dumps (WRD), Process Water Dams and other sources of interest. Water infiltrating into the contaminated sources after a rainfall event or seeping from the sources will create the opportunity for the water percolating through the sources to mobilise potential contaminants from the sources into the soil. Moreover, the mobilised contaminants could also be leached from the soil into the underlying weathered and fractured geology from where it has the potential to impact on the local groundwater.

The main areas ("probable hot spots") defining the source terms for the Harmony Free Sate Operations are depicted in Figure 8-1 and presented in Table 8-1.

No investigations on source term characterisation have been done previously. Certain specific assumptions have to be made therefore in order to simulate these sources in the model as discussed below. It should be noted that no quantitative calibration of the mass transport model is possible due to the lack of source term characterization. A qualitative analysis of the performance of the mass transport model is however provided at the end of this chapter of the report based on the observed sulphate concentrations at monitoring boreholes.

8.4.3 Source Terms Specified in the Feflow Model

'Source term' is an expression that is used to describe the quantity of contaminants released from a specific source to the various environmental compartments such as the atmosphere, geosphere or hydrosphere. A wide variety of methods can be used to derive the source term associated with a particular source, the choice of which depend on the environmental compartment under investigation and the information that is available for the particular source.

The focus of this study was to determine the potential impact of the Storage Facilities at the Harmony Free State Operations on the groundwater resources present in the study area. The impacts investigated include the effect of the Tailings Storage Facilities (TSF), Return Water Dams (RWD), Waste Rock Dumps (WRD), Process Water Dams and other sources of interest on the flow as well as the quality of groundwater. Groundwater quality impacts are often demonstrated by estimating the concentrations of water-soluble contaminants that are present in groundwater as a result of these contaminants being released from a particular source. In this study sulphate, which is present in appreciable quantities in gold tailings, was used to illustrate the release and dispersion of waterborne

contaminants to the groundwater from the Harmony Free State Operations Tailings Storage Facilities (TSF), Return Water Dams (RWD), Waste Rock Dumps (WRD), Process Water Dams and other sources of interest.

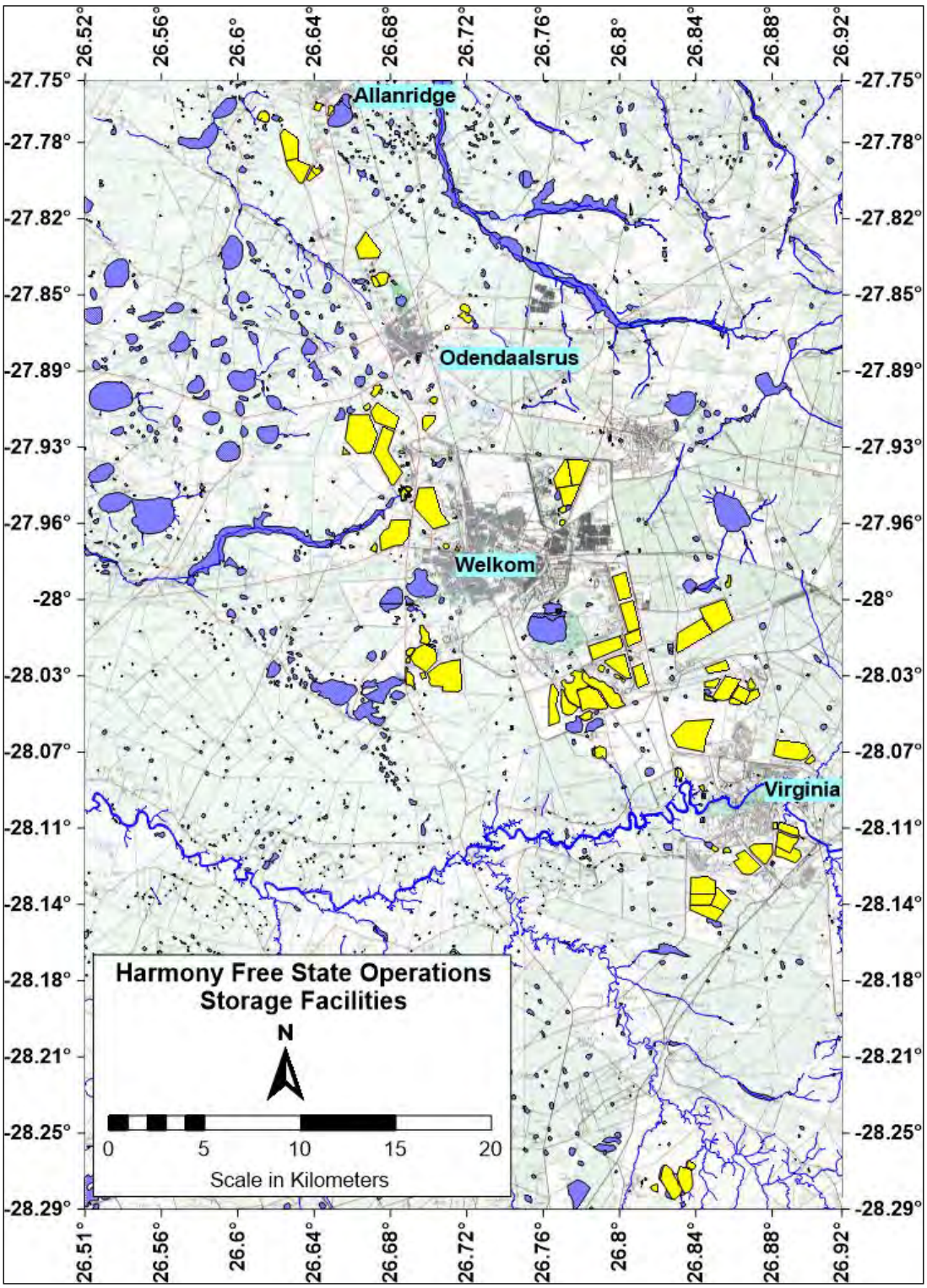


Figure 8-1 Map showing the distribution of Storage Facilities (coloured in yellow) associated with the Free State Operations of Harmony.

Table 8-1 Storage Facilities associated with the Free State Operations, showing their **ID's and** their Purpose/Description

No on Maps	ID	Source	Purpose/Description
1	H-G45	Dam 13 Return Water Dam	Return water dam
2	H_G42	12A Return Water Dam	Return water dam
3	H_G43	12B Return Water Dam	Return water dam
4	H_G44	12C Return Water Dam	Return water dam
5	S_G11	21/H3 Slimes Dam	Tailings storage facility (dormant - reprocessing)
6	H_G11	3.7 Million Dam	Process water from Nyala Shaft before draining into Two Million Dam
7	H_G34	ARM (Welkom) Slimes Dam	Tailings storage facility (dormant)
8	H_G18	ARM 6 Shaft Waste Rock Dump A - Unwashed	Waste rock dump (dormant)
9	H_G19	ARM 6 Shaft Waste Rock Dump B - Washed	Waste rock dump (dormant)
10	HF1	ARM Vlei	Process water dam
11	H_G16	Bambanani East (President Steyn 3 Shaft) Waste Rock Dump	Waste rock dump (dormant - footprint remaining)
12	H_G15	Bambanani West (President Steyn 3#) Waste Rock Dump	Waste rock dump (dormant - footprint remaining)
13	T_G15	Blue Return Water Dam	Return Water Dam
14	S_G3	Brand A Slimes Dam Complex	Tailings storage facility (Reclamation)
15	C_G4	Brand D Slimes Dam Complex	Tailings storage facility
16	C_G11	Calcine Slimes Dam 25	Tailings storage facility (dormant)
17	C_G12	Calcine Slimes Dam 27	Tailings storage facility (dormant - reclaimed)
18	C_G1	Convent Dam (upper and lower)	Storage of process water
19	H_G2	D-Dam	Pollution control dam and to be used by other harmony plants
20	S_G1	D-Dam (Virginia)	Storage of Excess water for reuse
21	H_G9	Duncan Dam	Process water dam
22	H_G20	Eland Shaft Waste Rock Dump	Waste rock dump (earmarked for backfilling)
23	H_G13	Eland Shaft Water Dam	Process water dam
24	T_G3	Emergency Overflow Ponds	Emergency dams for water from the return water dams
25	T_G6	Freddie's 3 Shaft Waste Rock Dump	Waste rock dump (dormant)
26	T_G7	Freddie's 6 Shaft Waste Rock Dump	Waste rock dump (dormant)
27	T_G12	Freddie's 9 Dam	Return Water Dam
28	T_G11	Freddie's 9 Shaft Slimes dam	Tailings storage facility (dormant)
29	T_G8	Freddie's 9 Shaft Waste Rock Dump	Waste rock dump
30	T_G13	Freddie's Return Water Dam	Return Water Dam
31	H_G25	FSN 1 Return Water Dam	Return water dam
32	H_G24	FSN 1 Slimes Dam	Tailings storage facility (dormant)
33	H_G27	FSN 2 Return Water Dam	Return water dam
34	H_G26	FSN 2 Slimes Dam	Tailings storage facility (dormant)
35	H_G28	FSN 3A Slimes Dam Complex	Tailings storage facility (dormant)

No on Maps	ID	Source	Purpose/Description
36	H_G29	FSN 3B Slimes Dam Complex	Tailings storage facility (dormant)
37	H_G30	FSN 4 Slimes Dam	Tailings storage facility (dormant)
38	H_G31	FSN 5 Slimes Dam	Tailings storage facility (dormant)
39	H_G33	FSN 6 Return Water Dam	Return water dam
40	H_G32	FSN 6 Slimes Dam	Tailings storage facility (dormant)
41	H_G36	FSS1 Slimes Dam	Tailings storage facility (dormant)
42	H_G37	FSS2 Slimes Dam	Tailings storage facility
43	C_G21	FSS3 Slimes Dam	Tailings storage facility (dormant)
44	H_G39	FSS4 Slimes Dam	Tailings storage facility (dormant)
45	C_G3	FSS5 Slimes Dam	Tailings storage facility
46	S_G17	FSS6 Slimes Dam	Tailings storage facility (dormant)
47	H_G40	FSS7 Slimes Dam	Tailings storage facility (dormant)
48	H_G41	FSS8 E&W Slime Dam Complex	Tailings storage facility (dormant)
49	C_G7	Harmony A-Dam	Return water dam
50	C_G8	Harmony B-Dam	Return water dam
51	C_G9	Harmony C-Dam	Return water dam
52	C_G10	Harmony D-Dam	Return water dam
53	H_G1	Harmony One Plant Surge Dam/Stormwater Dam	Storm water runoff and emergency dam
54	J_G4	Joel 3 South (Taung South) Shaft Waste Rock Dump	Waste rock dump (dormant)
55	J_G2	Joel 3 South Shaft TK1 Water Tank	Contains water abstracted from underground
56	J_G1	Joel Evaporation Dams	Excess water from the shafts and return water dam (emergency use only)
57	J_G6	Joel Return Water Dam	Return Water Dam
58	J_G3	Joel Sewage Plant	Sewage treatment plant
59	J_G5	Joel Slime Dam Complex	Tailings storage facility (dormant)
60	H_G3	Koffer Dam	Process water dam
61	H_G21	Kudu Shaft Waste Rock Dump	Waste rock dump (earmarked for backfilling)
62	T_G5	Lorraine 1 Old Waste Rock Dump	Waste rock dump (dormant)
63	H_G4	Masimong 4 Hot Water Dam	Excess water for reuse
64	H_G17	Masimong 4 Waste Rock Dump	Waste rock dump (dormant)
65	H_G10	Masons Vlei	Stormwater overflow from Nyala Shaft
66	T_G1	Million Gallon Dam	Water removed from underground at Target 1 Shaft
67	C_G6	No 23 (H4) Return Water Dam	Return water dam
68	C_G5	No. 23 (H4) Slimes Dam Complex	Tailings storage facility
69	C_G13	No. 30A Slimes Dam	Tailings storage facility (dormant)
70	C_G14	No. 30B Slimes Dam	Tailings storage facility (dormant)
71	C_G15	No. 31 Slimes Dam	Tailings storage facility (dormant)
72	C_G16	No. 32 Slimes Dam	Tailings storage facility (dormant)
73	C_G17	No. 33A Slimes Dam	Tailings storage facility (dormant)
74	C_G18	No. 33B Slimes Dam	Tailings storage facility (dormant)
75	C_G19	No. 34 A Slimes Dam	Tailings storage facility (dormant)

No on Maps	ID	Source	Purpose/Description
76	C_G20	No. 34 B Slimes Dam	Tailings storage facility (dormant)
77	T_G16	North-west (old) Return Water Dam	Return Water Dam
78	H_G22	Nyala Shaft Waste Rock Dump	Waste rock dump
79	S_G2	Saaiplaas 2 Shaft Waste Rock Dump	Waste rock dump (dormant)
80	S_G9	Saaiplaas No. 3 Return Water Dam	Return water dam
81	S_G10	Saaiplaas No. 5 Return Water Dam	Return water dam
82	S_G5	Saaiplaas Return Water Dams 1 & 2	Return water dams (dormant)
83	S_G4	Saaiplaas Slimes Dam Complex (Slimes dam 1, 2 & 3)	Tailings storage facilities (dormant)
84	S_G6	Saaiplaas Slimes Dam Complex 4	Tailings storage facilities
85	S_G7	Saaiplaas Slimes Dam Complex 5a & 5b	Tailings storage facilities (dormant)
86	S_G8	Saaiplaas Slimes Dam Complex 6	Tailings storage facilities (dormant)
87	J_G7	Settler Dams	Store slurry from underground
88	T_G14	South-east Return Water Dam (new clay lined dam)	Return Water Dam
89	S_G15	St Helena 1,2,3 Return Water Dam	Return water dam
90	S_G12	St Helena 1,2,3 Slimes Dam Complex	Tailings storage facility
91	S_G16	St Helena 1,2,3 Stormwater Dam	Return water dam
92	S_G14	St Helena 4 Return Water Dam	Return water dam
93	S_G13	St Helena 4 Slimes Dam	Tailings storage facilities (dormant)
94	T_F1	Swart Pan	Overflow from North-west (old) Return Water Dam
95	T_G9	Target 1 Tailings Storage Facility	Tailings storage facility
96	T_G10	Target 2 Tailings Storage Facility	Tailings storage facility
97	T_G2	Target 2 TSF Evaporation Dam	Excess water from Target 2 Shaft
98	T_G4	Target 3 Sewage Treatment Plant	Treatment of sewage from Target 3 Shaft and old Target Hostel
99	H_G7	Tshepong Shaft Dam	Process water dam
100	H_G8	Tshepong Stormwater Dam	Stormwater runoff
101	H_G23	Tshepong Waste Rock Dump	Waste rock dump
102	H_G12	Two Million Dam	Process water dam
103	C_G2	Virginia 2 Shaft Waste Rock Dump	Waste rock dump (dormant)
104	H_G5	Water Dam 33	Temporary storage of process water
105	H_G35	Welkom Return Water Dam (ARM TSF RWD)	Return water dam
106	H_G6	Wessel Pan	Excess water for reuse

The detailed source positions and ID numbers and Source names from Table 8-1 are depicted in Figure 8-2 to Figure 8-6.

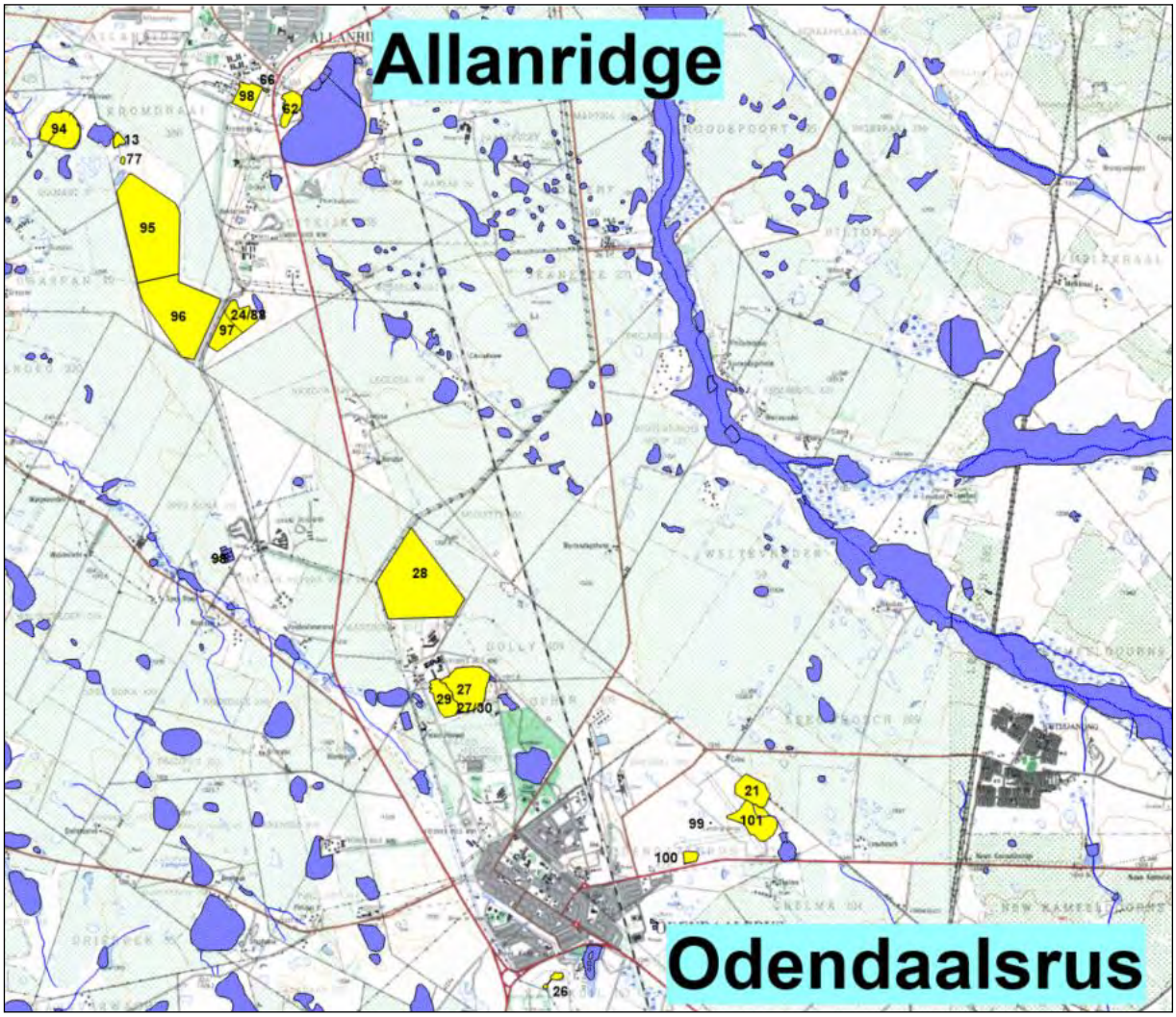


Figure 8-2 – **Source ID's (see** Table 8-1) of sources situated between Allanridge and Odendaalsrus.

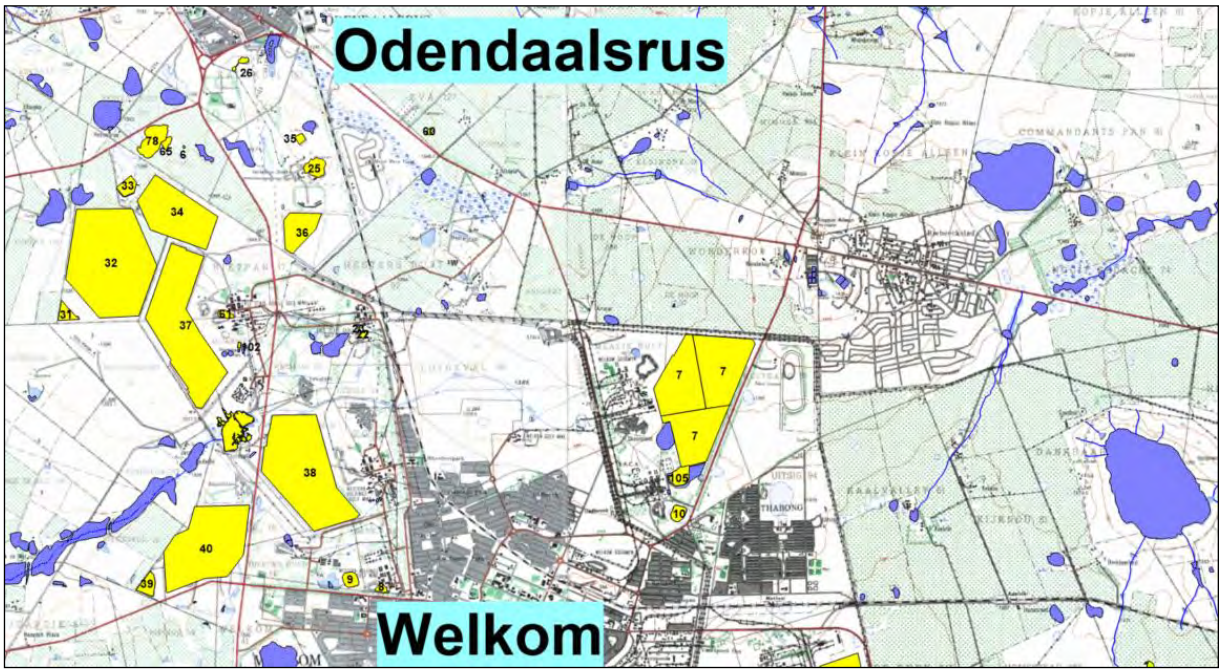


Figure 8-3 **– Source ID's (see** Table 8-1) of sources situated between Odendaalsrus and Welkom.

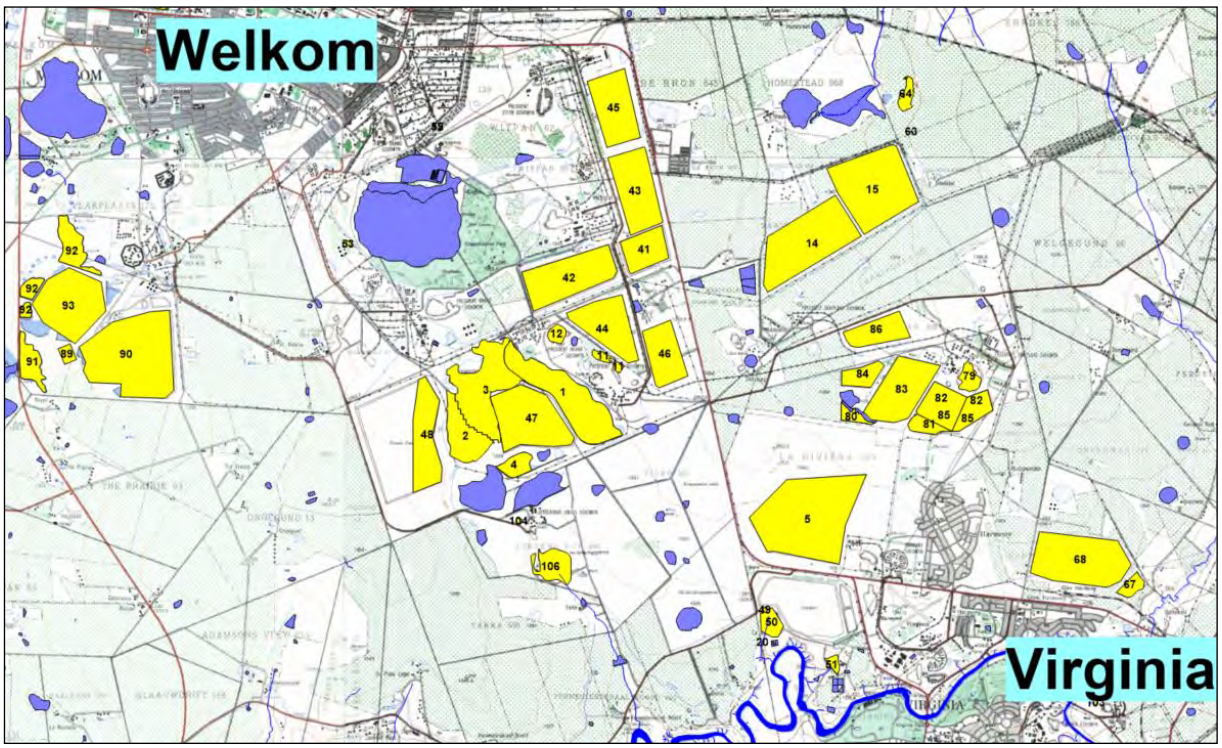


Figure 8-4 **– Source ID's (see** Table 8-1) of sources situated between Welkom and Virginia.

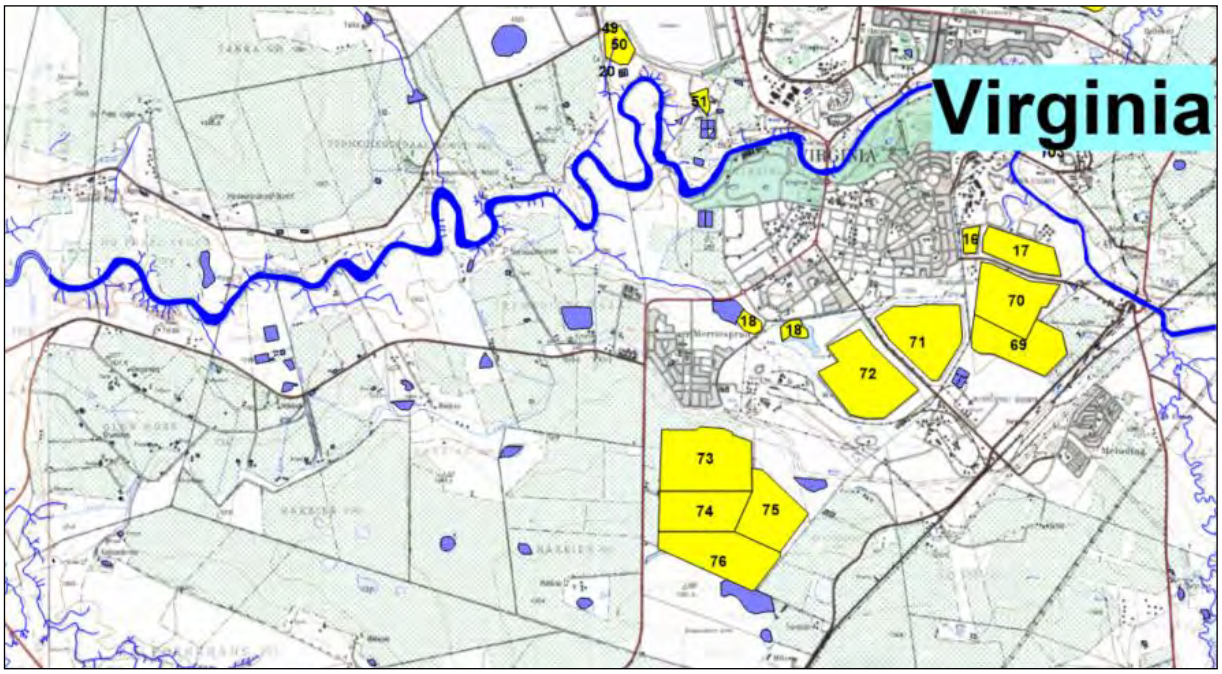


Figure 8-5 **– Source ID's (see** Table 8-1) of sources situated south of Virginia.

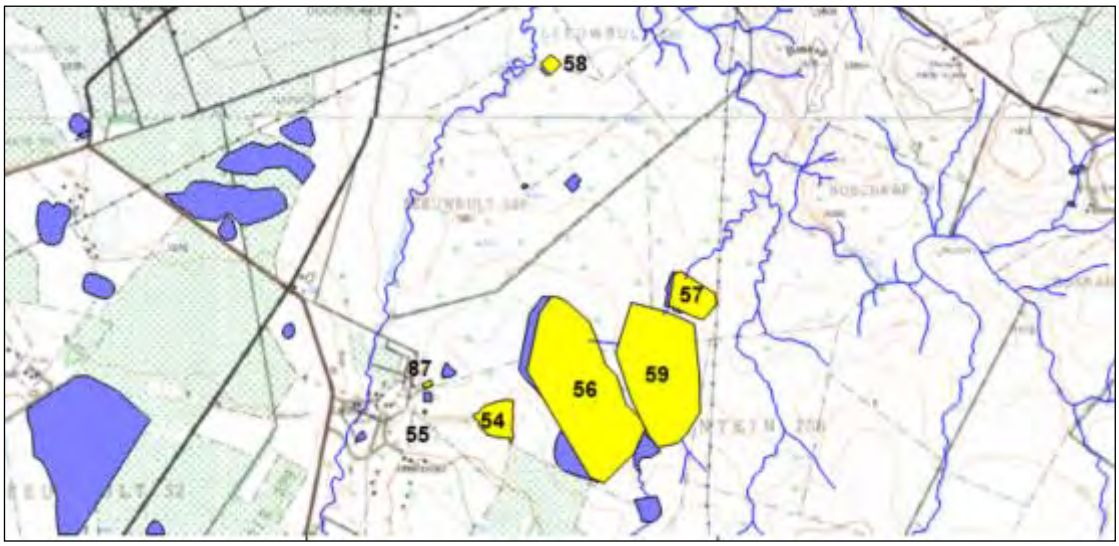


Figure 8-6 **– Source ID's (see** Table 8-1) of sources situated at Joel Mine.

The source terms are specified as a specified mass flux model boundary in the Feflow model. A specified mass flux boundary condition applies a pre-defined concentration (mg/l) multiplied by a seepage rate (m/d) as a mass load (mg/l*m/d) to a node. The model then simulates the concentration (mg/l) in the aquifer from the mass load specified and the mass load (g/d) to a receptor.

For the Harmony Free State Operations, the assumptions for each source are listed in Table 8-2. The table presents:

1. The source start date. Sources are active since 1967 exclusive of the Joel Mine sources which is assumed to be active since 1990.

2. The source closure date. Here it is assumed that all sources up to 2025 are all still active.

3. The seepage rates from the facilities. Here it is assumed that all TSF's are seeping at a rate of 0.0001423 m/d (9% of 577mm/annum rainfall). The same assumption holds for all the Return Water Dams and Process Water Dams.

4. For the waste rock dumps an infiltration rate of 4.742E-05 m/d (3% of 577mm/annum rainfall) is assumed.

5. For the Water Tank TK1, the sewage plants a seepage rate of 1E-06 m/d is assumed. (Represents a low number to cater for the occasional spill that might occur as it is assumed that these sources do not normally leak).

6. The source concentrations. Where possible, a source with an ESW monitoring point were linked with the observed SO_4 concentration. For the TSF concentrations the average SO_4 number based on the three samples from the ONE plant waste classification in the J&W report were assigned. The relevant temporal SO_4 concentrations observed at the relevant ESW observation points are attached in Appendix III.

Table 8-2 – Harmony Free State Operations assumed source terms.

No on Maps	SOURCE START DATE	SOURCE CLOSURE DATE	SEEPAGE RATE (m/d)	CONCENTRATION (mg/l)	FEFLOW source term (mg/l*m/d)
1	1967	N/A	0.0001423	642	0.091340
2	1967	N/A	0.0001423	1526	0.217110
3	1967	N/A	0.0001423	653	0.092905
4	1967	N/A	0.0001423	870	0.123778
5	1967	N/A	0.0001423	1942	0.276296
6	1967	N/A	0.0001423	1000	0.142274
7	1967	N/A	0.0001423	1942	0.276296
8	1967	N/A	4.742E-05	96	0.004553
9	1967	N/A	4.742E-05	96	0.004553
10	1967	N/A	0.0001423	241	0.034288
11	1967	N/A	4.742E-05	96	0.004553
12	1967	N/A	4.742E-05	96	0.004553
13	1967	N/A	0.0001423	1526	0.217110
14	1967	N/A	0.0001423	1942	0.276296
15	1967	N/A	0.0001423	1942	0.276296

No on Maps	SOURCE START DATE	SOURCE CLOSURE DATE	SEEPAGE RATE (m/d)	CONCENTRATION (mg/l)	FEFLOW source term (mg/l*m/d)
16	1967	N/A	0.0001423	1942	0.276296
17	1967	N/A	0.0001423	1942	0.276296
18	1967	N/A	0.0001423	1000	0.142274
19	1967	N/A	0.0001423	1287	0.183107
20	1967	N/A	0.0001423	1606	0.228492
21	1967	N/A	0.0001423	249	0.035426
22	1967	N/A	4.742E-05	96	0.004553
23	1967	N/A	0.0001423	249	0.035426
24	1967	N/A	0.0001423	96	0.013658
25	1967	N/A	4.742E-05	96	0.004553
26	1967	N/A	4.742E-05	96	0.004553
27	1967	N/A	0.0001423	544	0.077397
28	1967	N/A	0.0001423	1942	0.276296
29	1967	N/A	4.742E-05	96	0.004553
30	1967	N/A	0.0001423	1526	0.217110
31	1967	N/A	0.0001423	2285	0.325096
32	1967	N/A	0.0001423	1942	0.276296
33	1967	N/A	0.0001423	1671	0.237740
34	1967	N/A	0.0001423	1942	0.276296
35	1967	N/A	0.0001423	1942	0.276296
36	1967	N/A	0.0001423	1942	0.276296
37	1967	N/A	0.0001423	1942	0.276296
38	1967	N/A	0.0001423	1942	0.276296
39	1967	N/A	0.0001423	3293	0.468508
40	1967	N/A	0.0001423	1942	0.276296
41	1967	N/A	0.0001423	1942	0.276296
42	1967	N/A	0.0001423	1942	0.276296
43	1967	N/A	0.0001423	1942	0.276296
44	1967	N/A	0.0001423	1942	0.276296
45	1967	N/A	0.0001423	1942	0.276296
46	1967	N/A	0.0001423	1942	0.276296
47	1967	N/A	0.0001423	1942	0.276296
48	1967	N/A	0.0001423	1942	0.276296
49	1967	N/A	0.0001423	1000	0.142274
50	1967	N/A	0.0001423	1526	0.217110
51	1967	N/A	0.0001423	1526	0.217110
52	1967	N/A	0.0001423	1526	0.217110
53	1967	N/A	0.0001423	1000	0.142274
54	1990	N/A	4.742E-05	96	0.004553
55	1990	N/A	1.00E-06	186	0.000186
56	1990	N/A	0.0001423	978	0.139144
57	1990	N/A	0.0001423	1000	0.142274
58	1990	N/A	1.00E-06	46	0.000046

No on Maps	SOURCE START DATE	SOURCE CLOSURE DATE	SEEPAGE RATE (m/d)	CONCENTRATION (mg/l)	FEFLOW source term (mg/l*m/d)
59	1990	N/A	0.0001423	1942	0.276296
60	1967	N/A	0.0001423	327	0.046524
61	1967	N/A	4.742E-05	96	0.004553
62	1967	N/A	4.742E-05	96	0.004553
63	1967	N/A	0.0001423	1000	0.142274
64	1967	N/A	4.742E-05	96	0.004553
65	1967	N/A	0.0001423	213	0.030304
66	1967	N/A	0.0001423	1000	0.142274
67	1967	N/A	0.0001423	1526	0.217110
68	1967	N/A	0.0001423	1942	0.276296
69	1967	N/A	0.0001423	1942	0.276296
70	1967	N/A	0.0001423	1942	0.276296
71	1967	N/A	0.0001423	1942	0.276296
72	1967	N/A	0.0001423	1942	0.276296
73	1967	N/A	0.0001423	1942	0.276296
74	1967	N/A	0.0001423	1942	0.276296
75	1967	N/A	0.0001423	1942	0.276296
76	1967	N/A	0.0001423	1942	0.276296
77	1967	N/A	0.0001423	1526	0.217110
78	1967	N/A	4.742E-05	96	0.004553
79	1967	N/A	4.742E-05	96	0.004553
80	1967	N/A	0.0001423	2255	0.320828
81	1967	N/A	0.0001423	1356	0.192924
82	1967	N/A	0.0001423	1526	0.217110
83	1967	N/A	0.0001423	1942	0.276296
84	1967	N/A	0.0001423	1942	0.276296
85	1967	N/A	0.0001423	1942	0.276296
86	1967	N/A	0.0001423	1942	0.276296
87	1967	N/A	0.0001423	1000	0.142274
88	1967	N/A	0.0001423	1526	0.217110
89	1967	N/A	0.0001423	1526	0.217110
90	1967	N/A	0.0001423	1942	0.276296
91	1967	N/A	0.0001423	1526	0.217110
92	1967	N/A	0.0001423	1526	0.217110
93	1967	N/A	0.0001423	1942	0.276296
94	1967	N/A	0.0001423	1526	0.217110
95	1967	N/A	0.0001423	1942	0.276296
96	1967	N/A	0.0001423	1942	0.276296
97	1967	N/A	0.0001423	1000	0.142274
98	1967	N/A	1.00E-06	1000	0.001000
99	1967	N/A	0.0001423	1000	0.142274
100	1967	N/A	0.0001423	1000	0.142274
101	1967	N/A	4.742E-05	96	0.004553

No on Maps	SOURCE START DATE	SOURCE CLOSURE DATE	SEEPAGE RATE (m/d)	CONCENTRATION (mg/l)	FEFLOW source term (mg/l*m/d)
102	1967	N/A	0.0001423	1000	0.142274
103	1967	N/A	4.742E-05	96	0.004553
104	1967	N/A	0.0001423	1000	0.142274
105	1967	N/A	0.0001423	2376	0.338043
106	1967	N/A	0.0001423	2219	0.315706

8.4.4 Hydraulic Conductivity

Hydraulic conductivities (K) for the aquifer were specified according to the values obtained during the scenario of the steady state water level calibration (see subsection 7.5.4).

8.4.5 Kinematic Porosity Values

Definition of kinematic porosity: From the point of view of fluid displacement, the adhesive water may be viewed as part of the solid. The empty volume, where the water can circulate, is smaller than the total porosity: it defines the kinematic or effective porosity of a saturated medium.

One of the biggest uncertainties encountered during transport modelling of pollutants as in the case at the Harmony Free State Operations, is the kinematic porosity of the aquifer, as the aquifer displays no primary porosity characteristics. In the simulations kinematic porosity values of 0.01 was assigned. This is a typical value that is acceptable for Karoo type aquifers. A sensitivity analysis was subsequently performed on this parameter by halving (0.005) and doubling (0.02) of the specified value.

8.4.6 Longitudinal and Transversal Dispersivities

A longitudinal dispersivity value of 5 m was specified for the simulations (see Table D.3 – Field-Scale Dispersivities in Spitz and Moreno, 1996). Bear and Verruijt (1992) estimated the average transversal dispersivity to be 10 to 20 times smaller than the longitudinal dispersivity. An average value of 0.5 m was selected for this parameter during the simulations.

8.4.7 Hydraulic Heads

The hydraulic head values as calculated during the steady state simulations were specified as initial conditions in the model in order to calculate the average transport velocity (v) and Darcy flux (q) in the contaminant transport model.

8.4.8 Initial Sulphate Concentrations

Initial sulphate concentrations are set to 0 mg/l in the aquifer. This is done for purposes of assessing the incremental impacts from TSF deposition on the groundwater system over and above the background concentration (background values should therefore be added to arrive at total concentration values).

8.5 Mass Transport Transient Simulation over the period 1967-2025 Scenario 1 (Kinematic Porosity = 0.01).

Large uncertainties exist with regards to the behaviour and characteristics of the various source

terms for the different sources over the past 59 years of tailings deposition at the Harmony Free State Operations. Since this is the first attempt to assess the migration of contaminants from all the identified sources on such a regional scale, a simple approach was adopted in the specification of the source term as discussed in the previous section of this report. The simulation period covers the period 1967-2025 (a fifty-nine-year period). It is assumed that this is the maximum time period over which contamination could have occurred. Transient calibration evaluation of the mass transport model can only be done (attempted) once source term investigations for each of the different sources are completed.

8.5.1 Simulated Sulphate Concentration

Figure 8-7 to Figure 8-11 show the simulated development of the sulphate contaminant plumes after 5 (1972), 10 (1977), 20 (1987), 40 (2007) and 59 years (2025). This is indicative of the impact (migration direction and migration speed) that sources imposed over the past 59-years on the groundwater regime in the area.

8.5.2 Simulated Groundwater Velocity

The simulated groundwater velocity (Darcy Velocity) distribution is depicted in Figure 8-12. The Darcy velocity is simply defined by:

V (m/d) = K (m/d) x i where

V=Darcy Velocity

K = Hydraulic Conductivity

i = Hydraulic Gradient.

The Darcy Velocity ranges between $1.0x10^{-6}$ m/d and $4.4x10^{-3}$ m/d. To obtain the actual seepage velocity of a contaminant through the aquifer these numbers need to be divided by the kinematic porosity of the aquifer – for this scenario a kinematic porosity value of 0.01 was used which return actual flow velocities ranging between $1.0x10^{-4}$ m/d and 0.44m/d. From Figure 8-12 it is evident that the higher velocities in the aquifer are associated with areas where steeper groundwater gradients exist. To illustrate this groundwater flow contours were superimposed on the flow velocities in Figure 8-13. For the larger area, the Darcy Velocity ranges between 0.0002 m/d and 0.0008 m/d. The actual regional seepage velocity for this range is between 0.02 and 0.08 m/d. The regional travel distance over a fifty-nine-year period is therefore in the order of 420-1700m. Site specific travel distances from the relevant TSF's can be observed in Figure 8-7 to Figure 8-11.

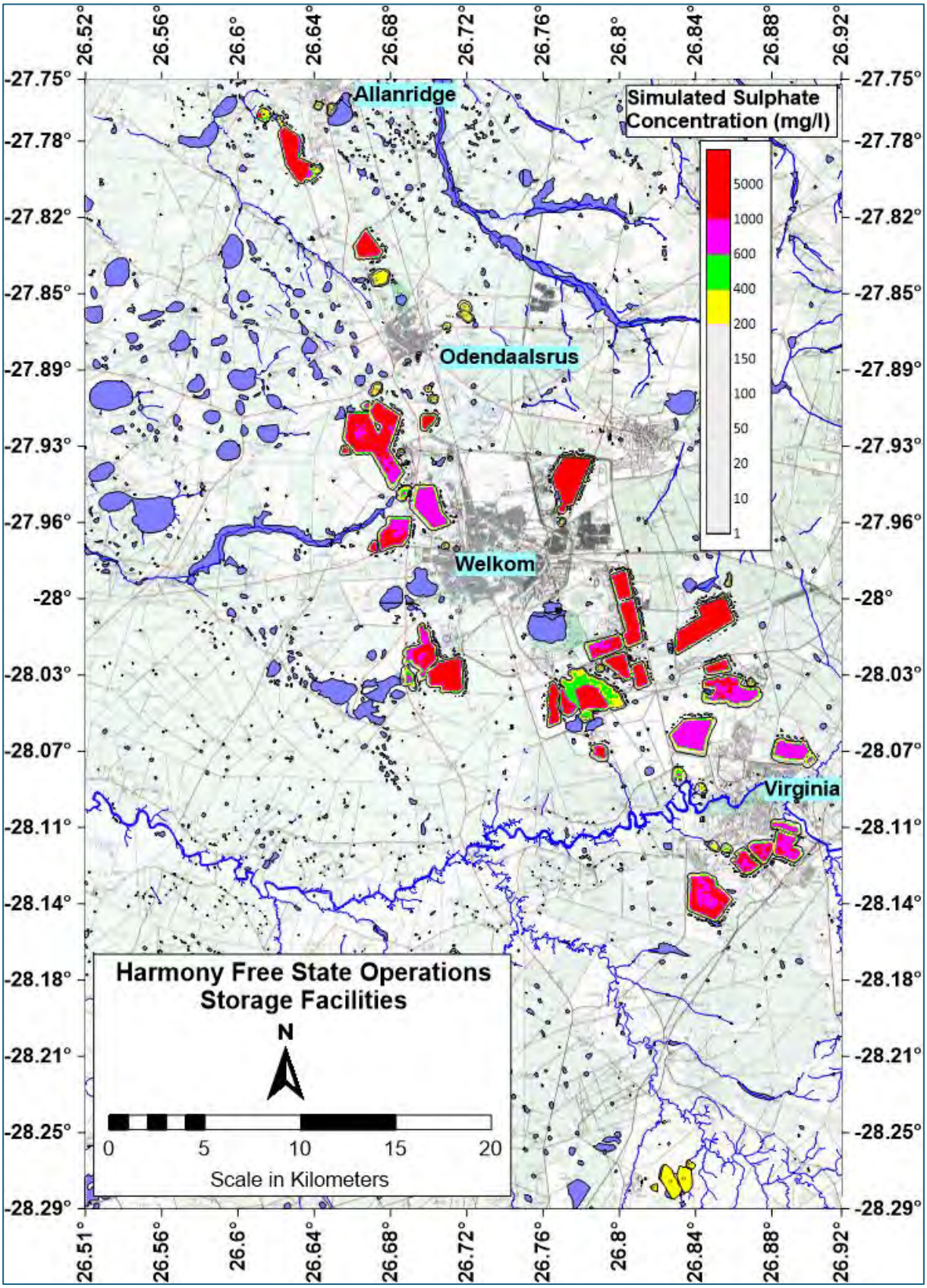


Figure 8-7 - Simulated Sulphate Plume January 1972 Scenario 1

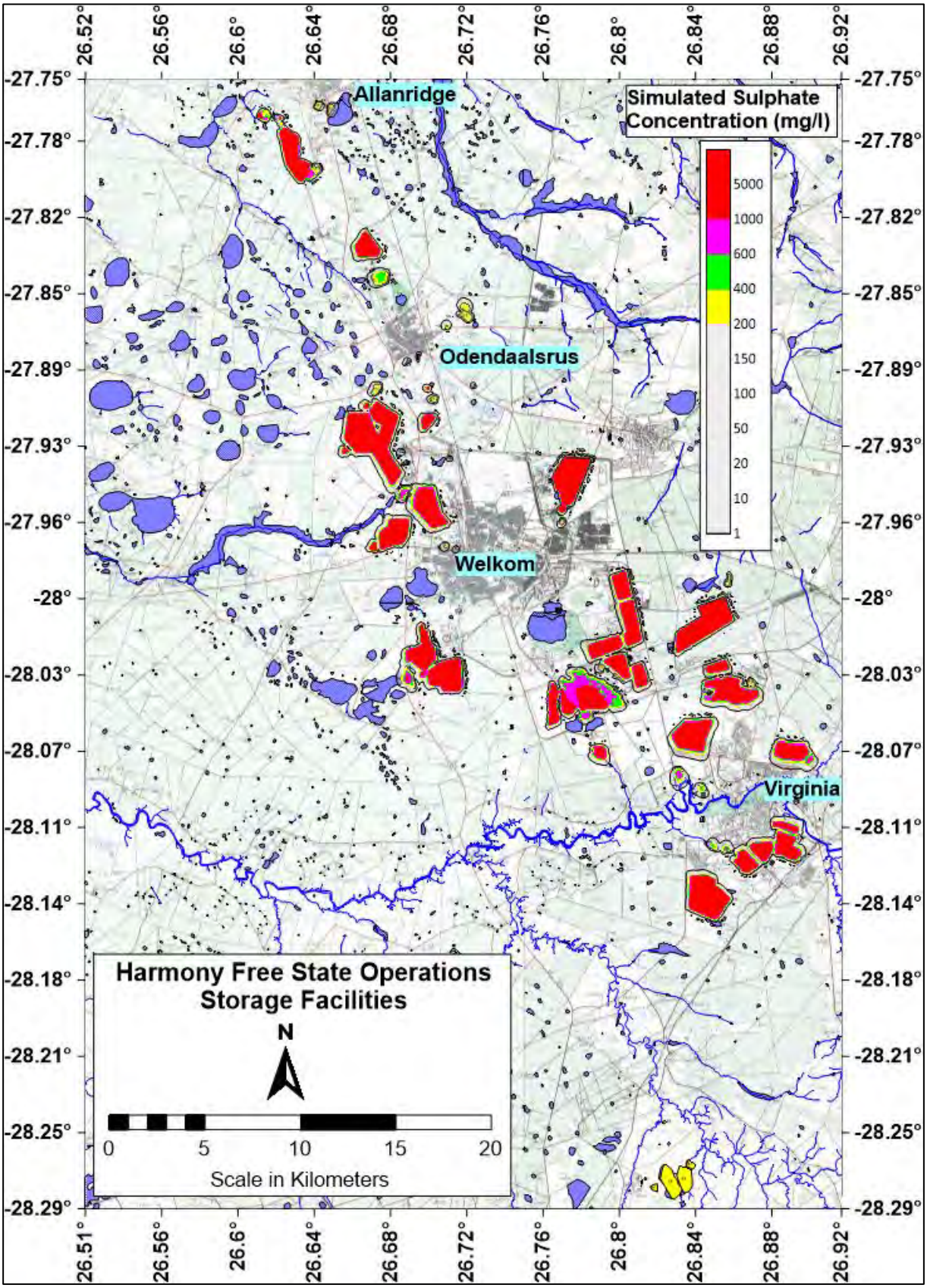


Figure 8-8 - Simulated Sulphate Plume January 1977-Scenario 1.

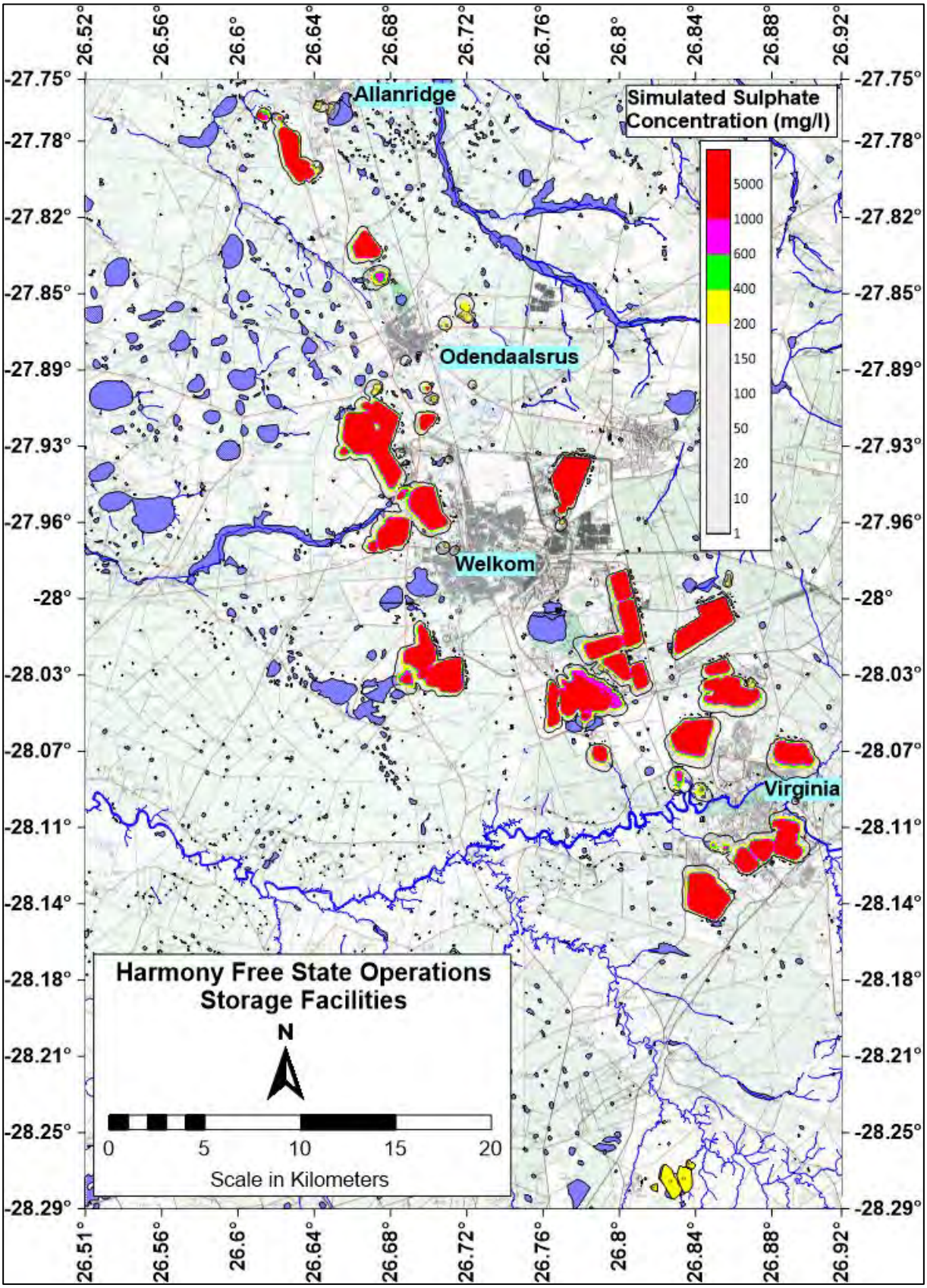


Figure 8-9 - Simulated Sulphate Plume January 1987-Scenario 1.

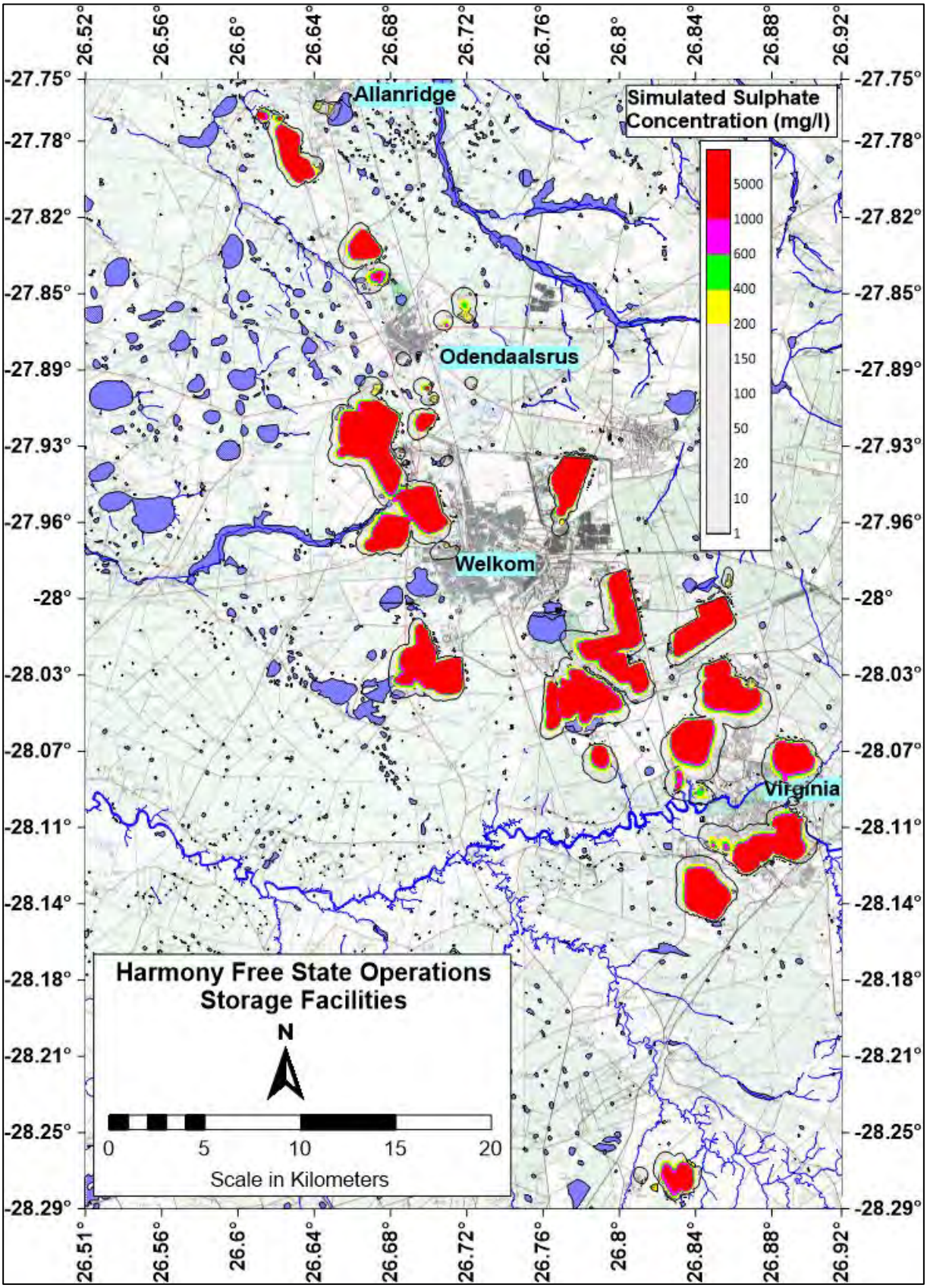


Figure 8-10 - Simulated Sulphate Plume January 2007-Scenario 1.

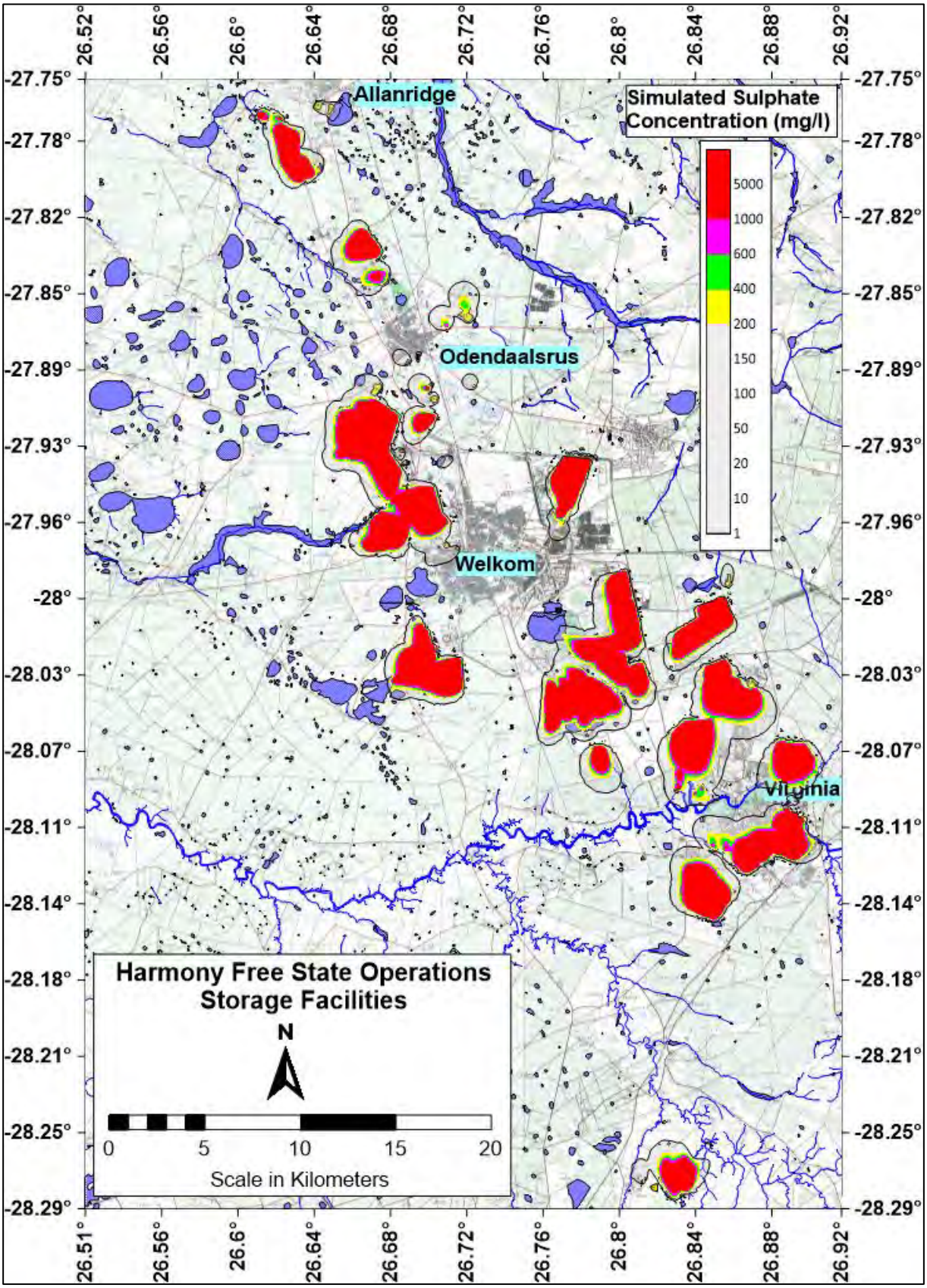


Figure 8-11 - Simulated Sulphate Plume December 2025-Scenario 1.

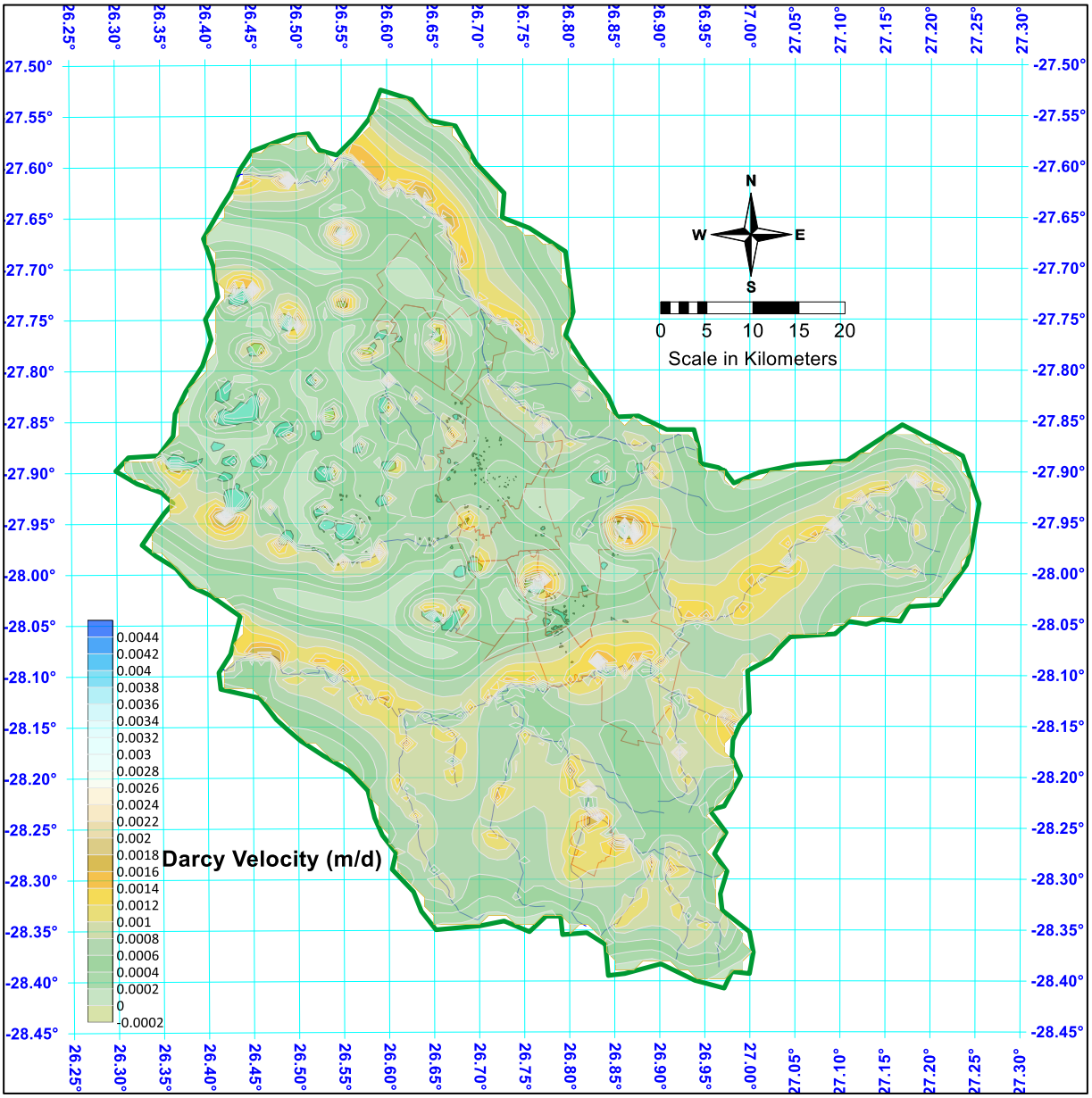


Figure 8-12 - Groundwater Flow Velocity Distribution (Darcy Velocity m/d).

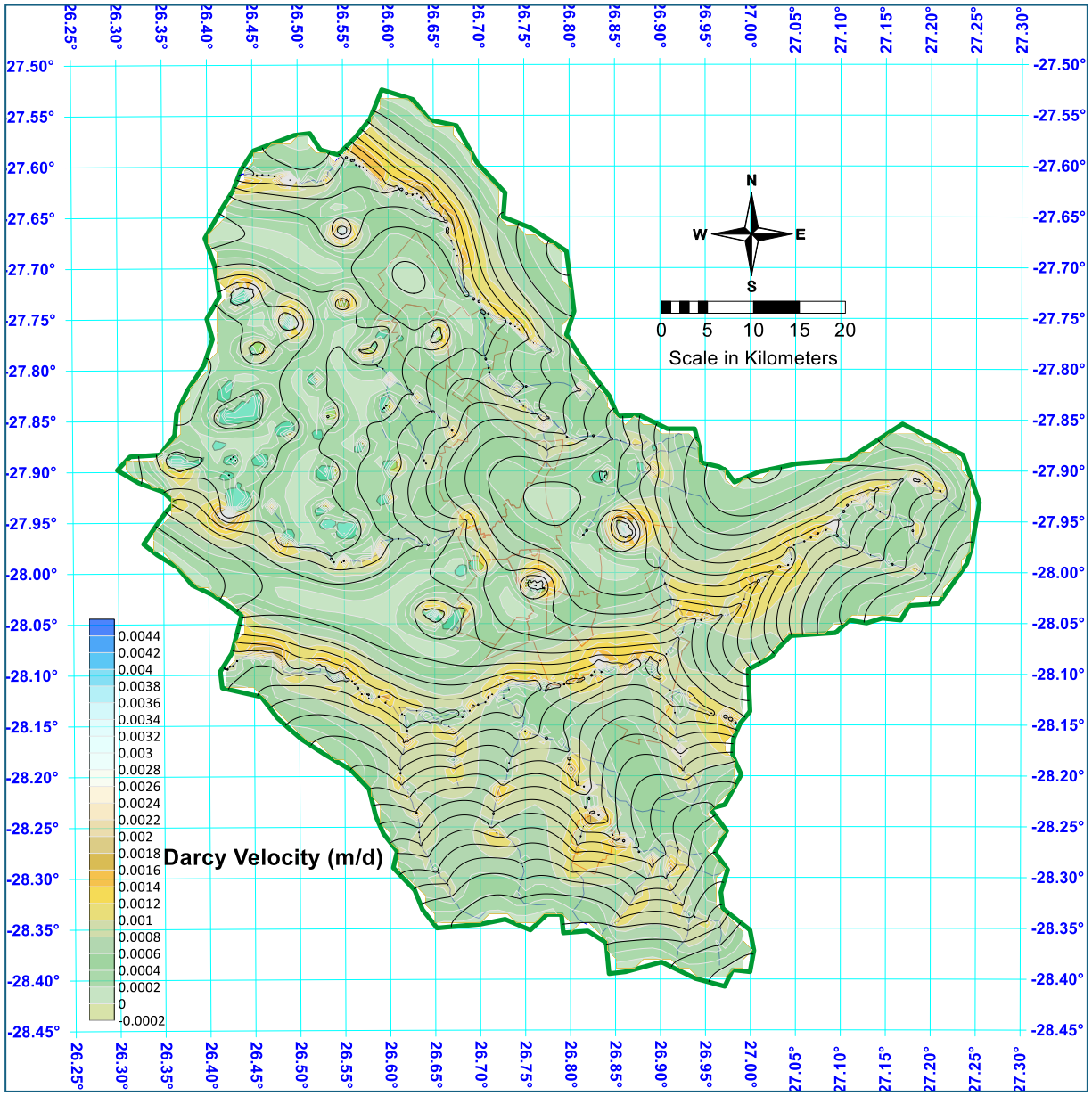


Figure 8-13 – Groundwater flow contours (black lines) superimposed on Groundwater Flow Velocity Distribution (Darcy Velocity m/d).

8.6 Mass Transport Transient Simulation over the period 1967-2025 Scenario 2 (Kinematic Porosity = 0.005).

8.6.1 Simulated Sulphate Concentration

Figure 8-14 shows the simulated sulphate concentration after 59 years (2025). This is indicative of the impact (migration direction and migration speed) that sources imposed over the past 59-years on the groundwater regime in the area. Compared to Figure 8-11 it is evident that by halving the kinematic porosity will increase the groundwater velocity by a factor of 2.

8.6.2 Simulated Groundwater Velocity

The Darcy Velocity ranges between 1.0×10^{-6} m/d and 4.4×10^{-3} m/d. To obtain the actual seepage

velocity of a contaminant through the aquifer these numbers need to be divided by the kinematic porosity of the aquifer – for this scenario a kinematic porosity value of 0.005 was used which return actual flow velocities ranging between $2.0x10^{-4}$ m/d and 0.88 m/d. From Figure 8-12 it is evident that the higher velocities in the aquifer are associated with areas where steeper groundwater gradients exist. To illustrate this groundwater flow contours were superimposed on the flow velocities in Figure 8-13. For the larger area, the Darcy Velocity ranges between 0.0002 m/d and 0.0008 m/d. The actual regional seepage velocity for this range is between 0.04 and 0.16 m/d. The regional travel distance over a fifty-nine-year period is therefore in the order of 840-3400m. Site specific travel distances from the relevant TSF's can be observed in Figure 8-14.

8.7 Mass Transport Transient Simulation over the period 1967-2025 Scenario 3 (Kinematic Porosity = 0.02).

8.7.1 Simulated Sulphate Concentration

Figure 8-15 shows the simulated sulphate concentration after 59 years (2025). This is indicative of the impact (migration direction and migration speed) that sources imposed over the past 59-years on the groundwater regime in the area. Compared to Figure 8-11 it is evident that by doubling the kinematic porosity will decrease the groundwater velocity by a factor of 2.

8.7.2 Simulated Groundwater Velocity

The Darcy Velocity ranges between $1.0x10^{-6}$ m/d and $4.4x10^{-3}$ m/d. To obtain the actual seepage velocity of a contaminant through the aquifer these numbers need to be divided by the kinematic porosity of the aquifer – for this scenario a kinematic porosity value of 0.02 was used which return actual flow velocities ranging between $5.0x10^{-5}$ m/d and 0.22 m/d. From Figure 8-12 it is evident that the higher velocities in the aquifer are associated with areas where steeper groundwater gradients exist. To illustrate this groundwater flow contours were superimposed on the flow velocities in Figure 8-13. For the larger area, the Darcy Velocity ranges between 0.0002 m/d and 0.0008 m/d. The actual regional seepage velocity for this range is between 0.01 and 0.04 m/d. The regional travel distance over a fifty-nine-year period is therefore in the order of 212-850m. Site specific travel distances from the relevant TSF's can be observed in Figure 8-15.

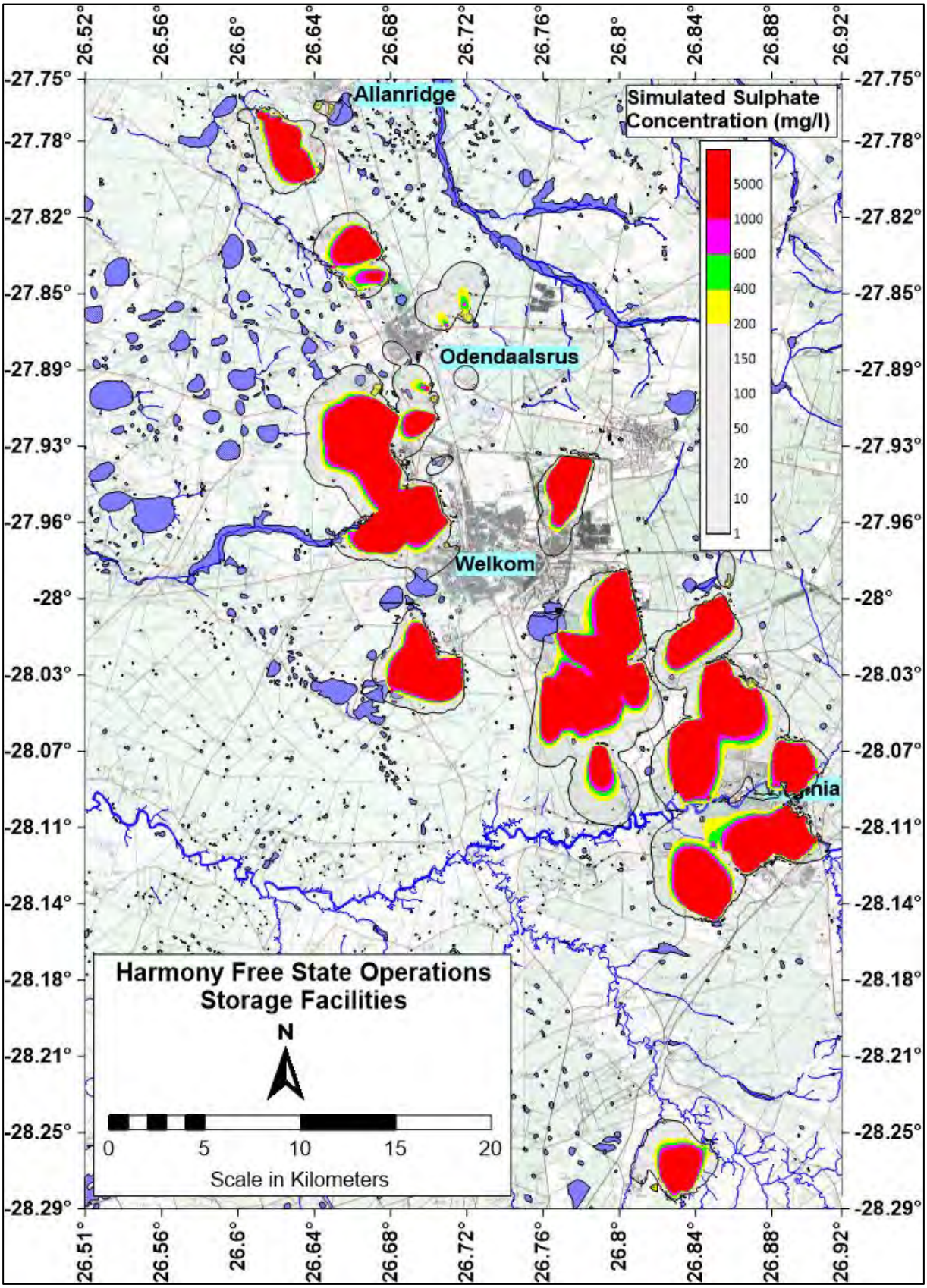


Figure 8-14 - Simulated Sulphate Plume December 2025-Scenario 2.

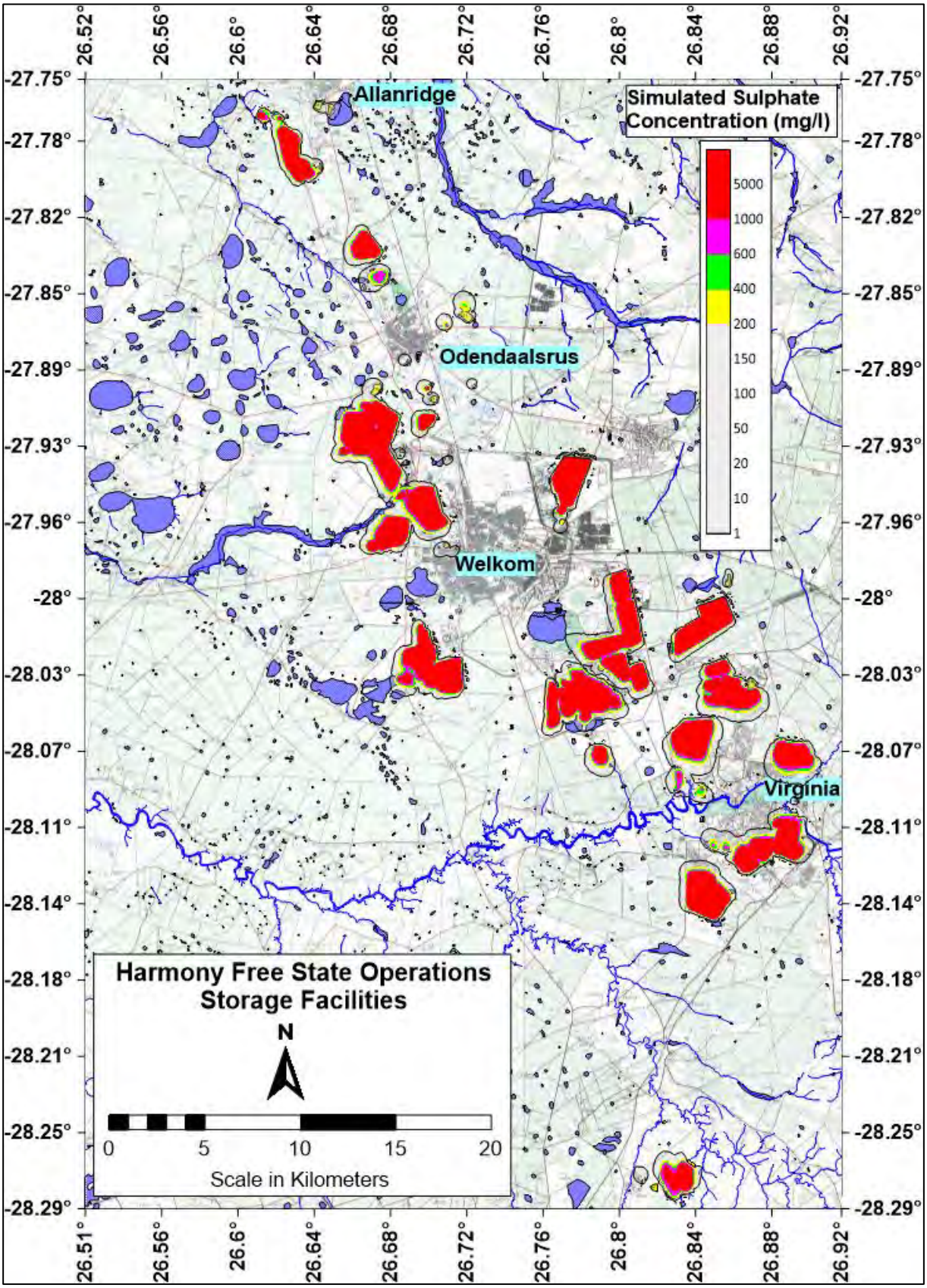


Figure 8-15 - Simulated Sulphate Plume December 2025-Scenario 3.

8.8 Observed Temporal Sulphate Concentrations in Boreholes

The temporally observed sulphate concentrations in boreholes are depicted in Appendix IV.

The different categories presented on the graphs depict the livestock water classes according to the SANS241 (2015) standard as indicated in Table 8-3.

Table 8-3 Livestock Water Standard for Sulphate according to the SANS (2015).

Description	Sulphate Quality (mg/l)	Colour on Map/Graph/Table
Below Limit	0-1000	White
Above Limit	>1000	Red

From the graphs presented in Appendix IV a representative water class was assigned for each borehole according to the representative quality according to the SANS (2015) standard. Where the quality at a particular location border on the boundary between two adjacent water classes, the poorer class were chosen which provides for a more conservative number. The water class classification number thus obtained for each of the boreholes are shown in Table 8-4 and spatially depicted in Figure 8-16. From the map presented in Figure 8-16 it is now fairly easily distinguishable where poorer (and affected) areas are situated and their relationship with the positions of the sources. In general, the poorer qualities can be clearly associated with the sources. It is also possible to identify the unaffected areas relatively accurately.

8.9 Qualitative Assessment of Simulated Sulphate Plume Migration and Observed Sulphate Concentration Observed in Boreholes

The primary objective of the study is to establish a preliminary model which can predict the migration direction and migration velocity from the sources. Since the model is not calibrated to particular sulphate concentrations due to the lack of developed source terms for the different sources only a qualitative judgement can be provided with regards to the relevance of the model based on the observed field concentrations obtained from the monitoring boreholes. For this purpose, a map was created where the simulated plumes are overlain on the monitoring borehole water classes as depicted in Figure 8-17. A direct comparison of the two data sets is possible to assess areas being contaminated according to the simulations and areas being contaminated according to the field observations. This map in general indicates that the simulated plumes overlap with areas of poorer observed water qualities. It is also evident from the map that in most cases where observed qualities seem unaffected that the model prediction agrees. These statements are backed up by a more detailed analysis following in the subsequent sections of this report.

Table 8-4 Representative Livestock Water Class (SANS, 2015) assigned at the monitoring boreholes

BH ID	X-co-ordinate	Y-co-ordinate	SO4 mg/l	SANS (2015) Livestock Class
B 2N1	-38482.24	-3073846.92	126.48	Below Limit
A7	-34941.65	-3073783.90	4439.21	Above Limit
BH D1	-12607.33	-3127739.48	39.27	Below Limit
BH D2	-13996.90	-3128824.35	28.30	Below Limit
BH FS3	-19394.38	-3099286.34	858.37	Below Limit
BH J2	-15531.84	-3127112.17	80.35	Below Limit
BH P1	-13481.48	-3104514.15	553.64	Below Limit
BH P9	-11646.10	-3104487.59	68.56	Below Limit
BH 1A	-19397.87	-3099289.97	1418.00	Above Limit
BH 1	-15852.88	-3106012.52	1061.38	Above Limit
BH 10	-22134.29	-3098998.88	1991.38	Above Limit
BH 11	-17672.11	-3100353.34	757.08	Below Limit
BH 113	-36739.74	-3090345.05	72.83	Below Limit
BH 129	-24211.54	-3089898.39	92.38	Below Limit
BH 131	-25866.90	-3088721.29	85.91	Below Limit
BH 132	-21609.74	-3089411.37	120.91	Below Limit
BH 136	-32756.08	-3095075.46	3130.81	Above Limit
BH 137	-32360.52	-3094395.30	2842.30	Above Limit
BH 14	-21001.78	-3101830.47	1342.52	Above Limit
BH 144	-34226.73	-3088924.38	2446.10	Above Limit
BH 164	-38347.09	-3093190.48	281.81	Below Limit
BH 170	-35636.58	-3085235.68	260.33	Below Limit
BH 174	-39661.47	-3088259.49	650.72	Below Limit
BH 176	-39902.47	-3087244.74	641.40	Below Limit
BH 177	-34261.60	-3084544.00	296.46	Below Limit
BH 179	-35841.63	-3083701.74	64.21	Below Limit
BH 185	-22745.81	-3102130.41	2389.94	Above Limit
BH 186	-22129.79	-3100696.59	340.40	Below Limit
BH 188	-23289.59	-3101730.04	43.33	Below Limit
BH 19	-20323.93	-3096125.74	185.65	Below Limit
BH 192	-14218.69	-3091930.44	9.69	Below Limit
BH 194	-11744.92	-3094200.80	40.70	Below Limit
BH 195	-27748.80	-3083236.22	1338.68	Above Limit
BH 198	-28116.80	-3082862.75	81.32	Below Limit
BH 19H	-7830.44	-3110494.08	48.06	Below Limit
BH02	-18347.31	-3100340.58	1715.18	Above Limit
BH 206	-39082.83	-3096674.51	460.91	Below Limit
BH 208	-39556.28	-3089649.03	581.71	Below Limit
BH 211	-30368.18	-3093032.86	2920.81	Above Limit
BH 227	-24949.52	-3100289.93	77.41	Below Limit
BH 24	-11941.65	-3102229.60	62.98	Below Limit

BH ID	X-co-ordinate	Y-co-ordinate	SO4 mg/l	SANS (2015) Livestock Class
BH 26	-12283.15	-3101887.63	101.10	Below Limit
BH 27	-15815.90	-3101348.75	323.28	Below Limit
BH 28H	-9189.65	-3107749.75	62.17	Below Limit
BH 2A	-18347.16	-3100338.96	228.69	Below Limit
BH 3	-19417.89	-3108678.11	117.08	Below Limit
BH 31H	-15771.23	-3111815.48	84.37	Below Limit
BH 33	-17348.08	-3100190.95	25.90	Below Limit
BH 36H	-17060.39	-3121614.31	38.88	Below Limit
BH 37H	-9380.13	-3117577.67	29.88	Below Limit
BH 39H	-5692.08	-3105522.84	85.00	Below Limit
BH 3A	-19101.27	-3101115.27	337.65	Below Limit
BH 3B	-19106.18	-3101121.13	738.29	Below Limit
BH04	-20027.78	-3106881.90	1155.32	Above Limit
BH 41	-33441.89	-3090617.11	1506.30	Above Limit
BH 43	-31827.24	-3091516.54	4693.67	Above Limit
BH 46	-32431.75	-3093625.60	3425.87	Above Limit
BH 47	-34436.07	-3092598.38	106.79	Below Limit
BH 55	-32060.54	-3096602.00	302.93	Below Limit
BH 59	-18019.94	-3107020.99	341.00	Below Limit
BH 6	-20924.82	-3106169.00	90.74	Below Limit
BH 60	-17678.61	-3108346.03	106.50	Below Limit
BH 71	-33611.19	-3087657.14	205.51	Below Limit
BH 75	-41470.72	-3091987.04	574.46	Below Limit
BH 80H	-7514.51	-3112870.09	46.12	Below Limit
BH 81H	-8384.01	-3114736.79	41.04	Below Limit
BH 82H	-9103.95	-3115952.36	29.72	Below Limit
BH 85	-40050.54	-3075160.60	111.45	Below Limit
BH 86	-39698.10	-3076697.06	51.76	Below Limit
BH 88	-41839.11	-3075367.97	22.52	Below Limit
BH 88H	-19577.97	-3111444.93	92.85	Below Limit
BH 91	-29859.07	-3095067.91	789.93	Below Limit
BH A1	-38559.69	-3072738.37	1863.71	Above Limit
BH A2	-37367.63	-3073763.40	2012.69	Above Limit
BH A3	-37237.03	-3074299.24	1572.10	Above Limit
BH A5	-36074.08	-3076117.46	3393.43	Above Limit
A6	-35046.86	-3072594.65	774.98	Below Limit
BH B38N	-38931.70	-3072428.96	323.89	Below Limit
BH B41S	-39274.20	-3075567.47	108.00	Below Limit
BH B7	-37785.27	-3075571.04	88.27	Below Limit
BH D1	-12581.08	-3127694.97	39.30	Below Limit
BH D2	-14014.97	-3128713.51	29.50	Below Limit
BHH01	-15310.66	-3107488.71	48.61	Below Limit
BHH02	-16343.22	-3107081.26	486.56	Below Limit

BH ID	X-co-ordinate	Y-co-ordinate	SO4 mg/l	SANS (2015) Livestock Class
BHH03	-16581.46	-3106948.49	890.70	Below Limit
J2	-15531.75	-3127112.25	120.00	Below Limit
BH P1	-13446.83	-3104466.92	554.00	Below Limit
BH P9	-11646.06	-3104481.98	89.20	Below Limit
BH VP1	-34924.62	-3073094.90	1245.45	Above Limit
BH VP2	-33408.56	-3071706.63	1392.77	Above Limit
BH KLM 2	-16550.51	-3127445.41	8.18	Below Limit
BH KLM 3	-15926.97	-3127403.20	1077.273	Above Limit
BH KLM 4	-15690.10	-3128636.22	1812.17	Above Limit
PBH1D	-23463.98	-3090774.97	914.93	Below Limit
PBH1S	-23464.96	-3090774.97	1141.08	Above Limit
PBH2D	-23740.02	-3090542.79	290.14	Below Limit
PBH2S	-23739.04	-3090539.46	76.51	Below Limit
STHH1	-27803.21	-3099811.68	114.02	Below Limit
STHH 2	-29478.64	-3101849.55	1798.21	Above Limit
STHH 4	-29330.78	-3100546.42	6973.79	Above Limit
STHM 2	-29662.56	-3102807.39	78.66	Below Limit
STHM3	-29718.00	-3102578.00	1372.79	Above Limit

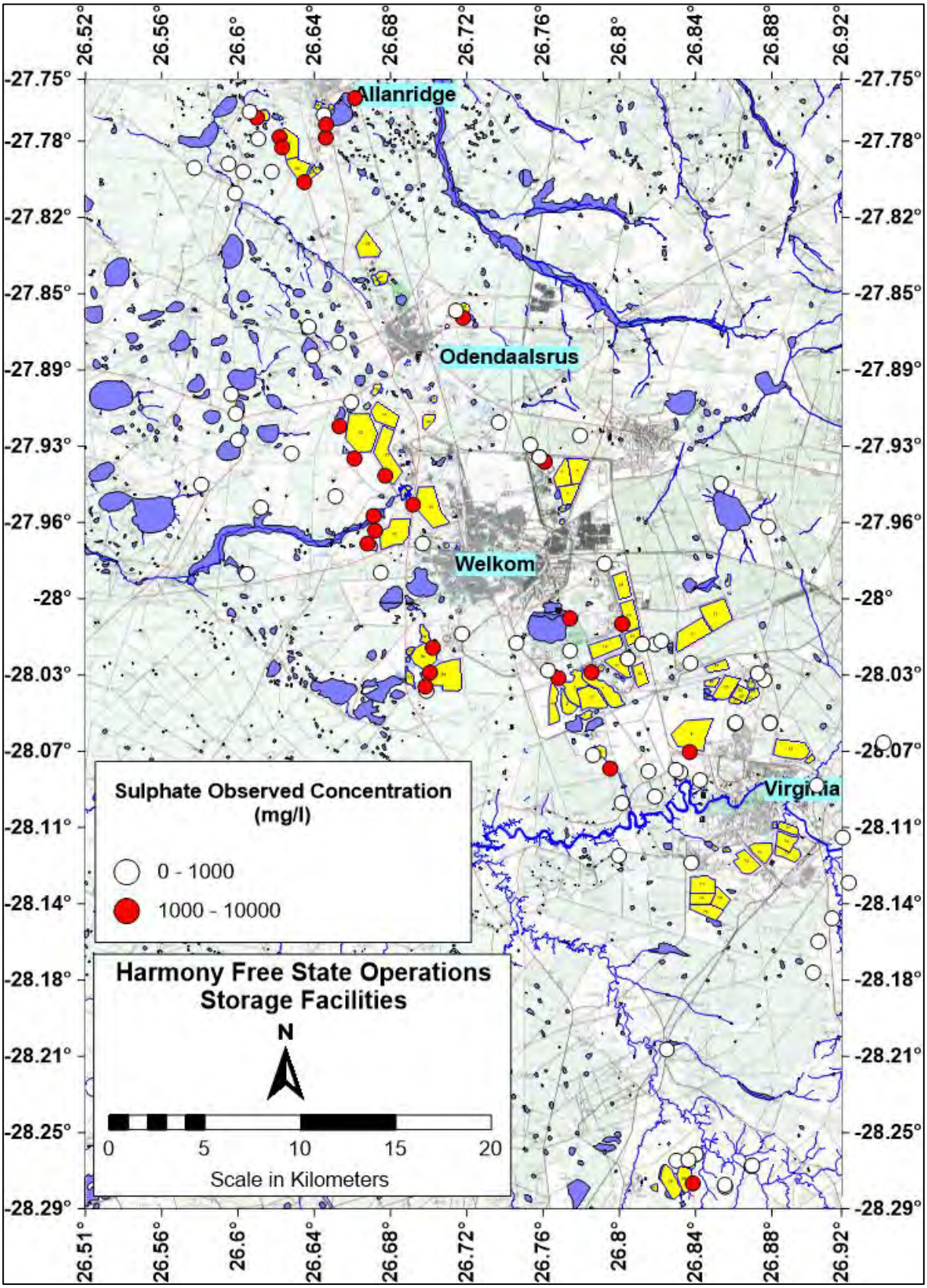


Figure 8-16 Map showing borehole water sulphate concentrations expressed in terms of the SANS (2015) livestock water standard. Yellow areas indicate source footprint positions.

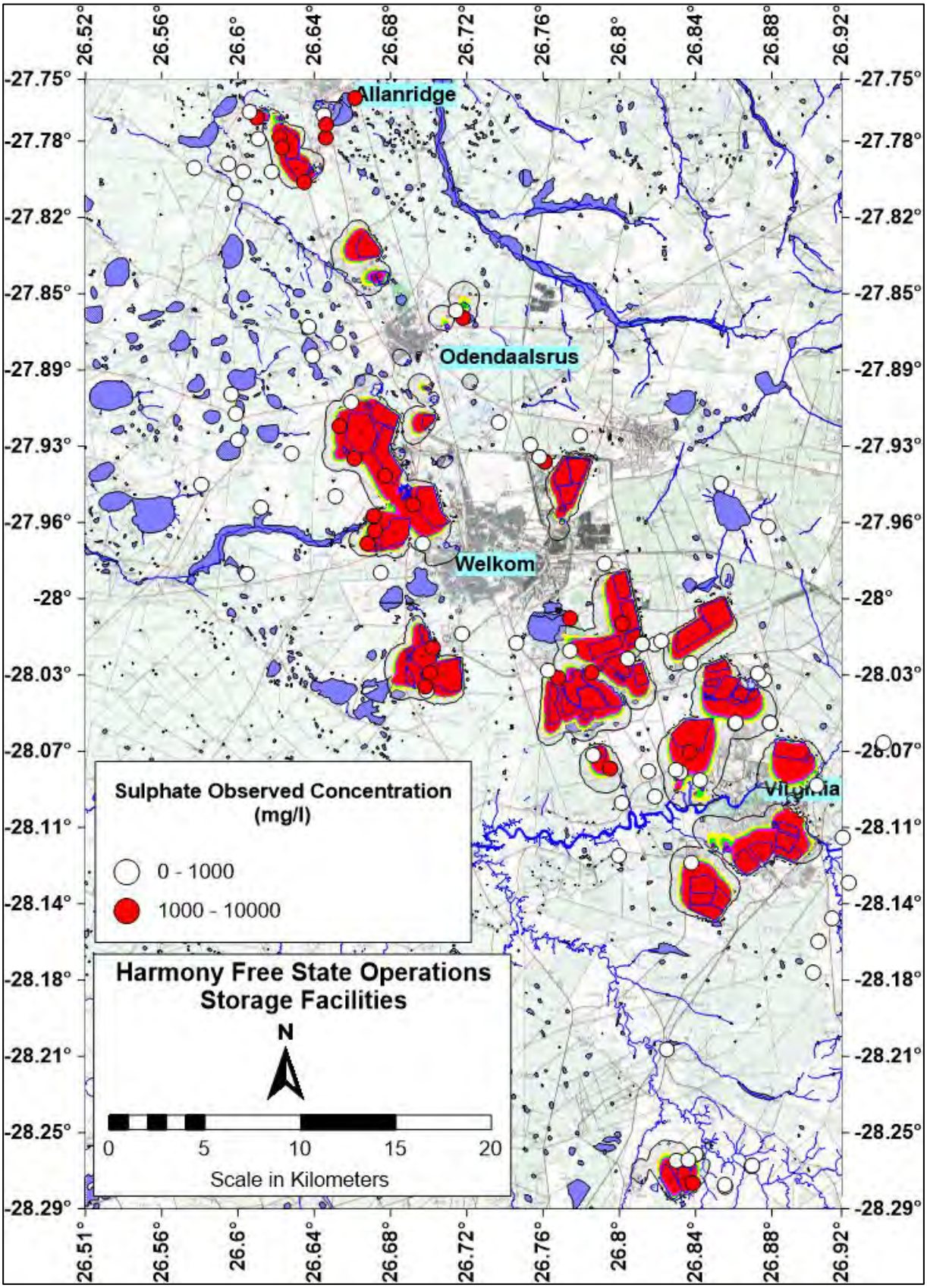


Figure 8-17 Simulated plumes overlain on borehole water sulphate concentrations expressed in terms of the SANS (2015) livestock water standard. Source footprints are indicated by blue lines.

9 Detailed Analysis of Contamination Impact from the Source Areas

9.1 Introduction

The simulations depicting contamination migration conducted thus far are based upon a regional perspective across the Harmony Free State Operations. This section of the report will analyse in more detail the contamination impact from the identified sources depicted in Table 8-1 according to the Source – Pathway – Receptor (SPR) approach. The study area will be systematically analysed in detail from the Target Operation in the north to the Joel Operation in the south.

9.2 Operations in the Target Area

9.2.1 Location

The Target Operations are situated in the vicinity of the mining town of Allanridge to the west and southwest of the Stink Pan (which is to the southeast of Allanridge) as depicted on Figure 9-1.

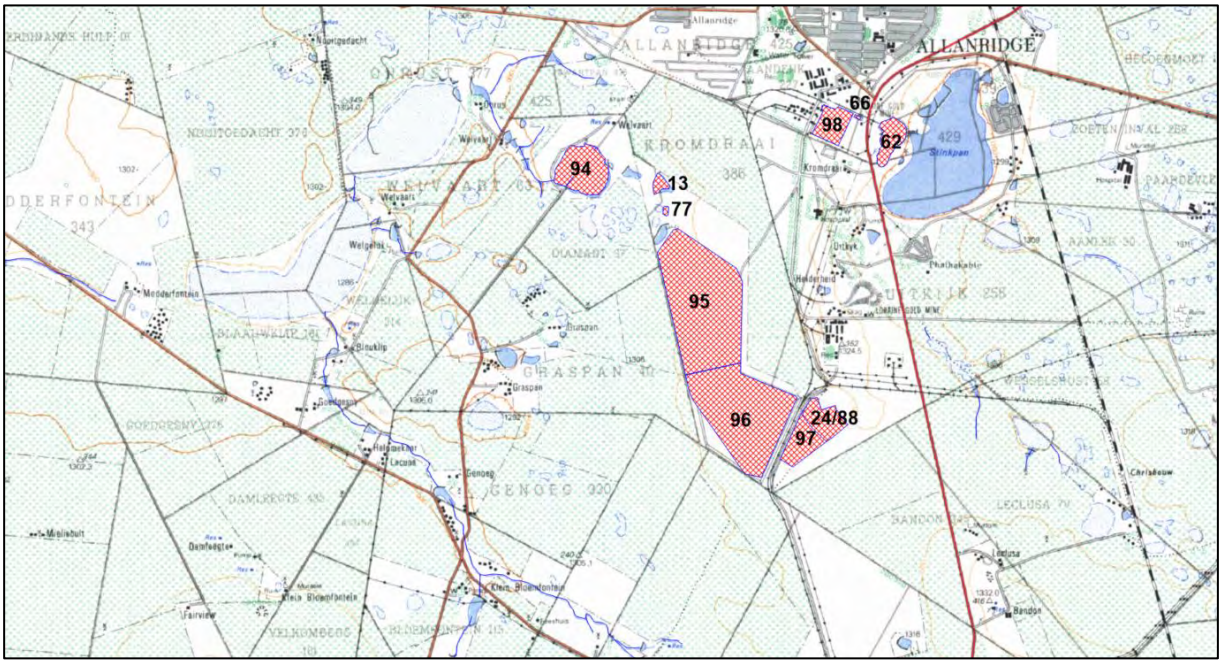


Figure 9-1 – Location of the Harmony Free State Target Operation. Sources are indicated by the red cross-hatched areas.

9.2.2 Sources

The sources depicted on Figure 9-1 are described in Table 9-1. The main sources in terms of size and contamination are the Target No. 1 and 2 Tailings Storage Facilities and the Target 2 TSF Evaporation Dam followed by Swart Pan which receives the overflow from the Northwest (old) Return Water Dam.

Table 9-1 – Target Operations source description.

No on Maps	ID	Source	Purpose/Description	SEEPAGE RATE (m/d)	CONCENTRATION (mg/l)	FEFLOW (mg/l*m/d)
94	T_F1	Swart Pan	Overflow from North-west (old) Return Water Dam	0.000142274	1526	0.217110
95	T_G9	Target 1 Tailings Storage Facility	Tailings storage facility	0.000142274	1942	0.276296
96	T_G10	Target 2 Tailings Storage Facility	Tailings storage facility	0.000142274	1942	0.276296
97	T_G2	Target 2 TSF Evaporation Dam	Excess water from Target 2 Shaft	0.000142274	1000	0.142274
98	T_G4	Target 3 Sewage Treatment Plant	Treatment of sewage from Target 3 Shaft and old Target Hostel	1.00E-06	1000	0.001000
88	T_G14	South-east Return Water Dam (new clay lined dam)	Return Water Dam	0.000142274	1526	0.217110
62	T_G5	Lorraine 1 Old Waste Rock Dump	Waste rock dump (dormant)	4.74247E-05	96	0.004553
66	T_G1	Million Gallon Dam	Water removed from underground at Target 1 Shaft	0.000142274	1000	0.142274
13	T_G15	Blue Return Water Dam	Return Water Dam	0.000142274	1526	0.217110
77	T_G16	North-west (old) Return Water Dam	Return Water Dam	0.000142274	1526	0.217110

9.2.3 Groundwater Elevation Contours and Flow Directions

The groundwater elevation contours and groundwater flow directions are depicted in Figure 9-2. The regional groundwater flow follows the regional topography which is from southeast to northwest. Locally however, two depressions in the groundwater elevation contours are visible from Figure 9-2. The first one is the Stink Pan to the southeast of Allanridge and the second one is an unnamed surface depression situated west of the Target TSF's where the borders of the farms Nooitgedacht, Welvaard, Welgeluk and Blaauwklip meet. From a groundwater flow point of view, these two groundwater depressions will form Receptors in the SPR analysis.

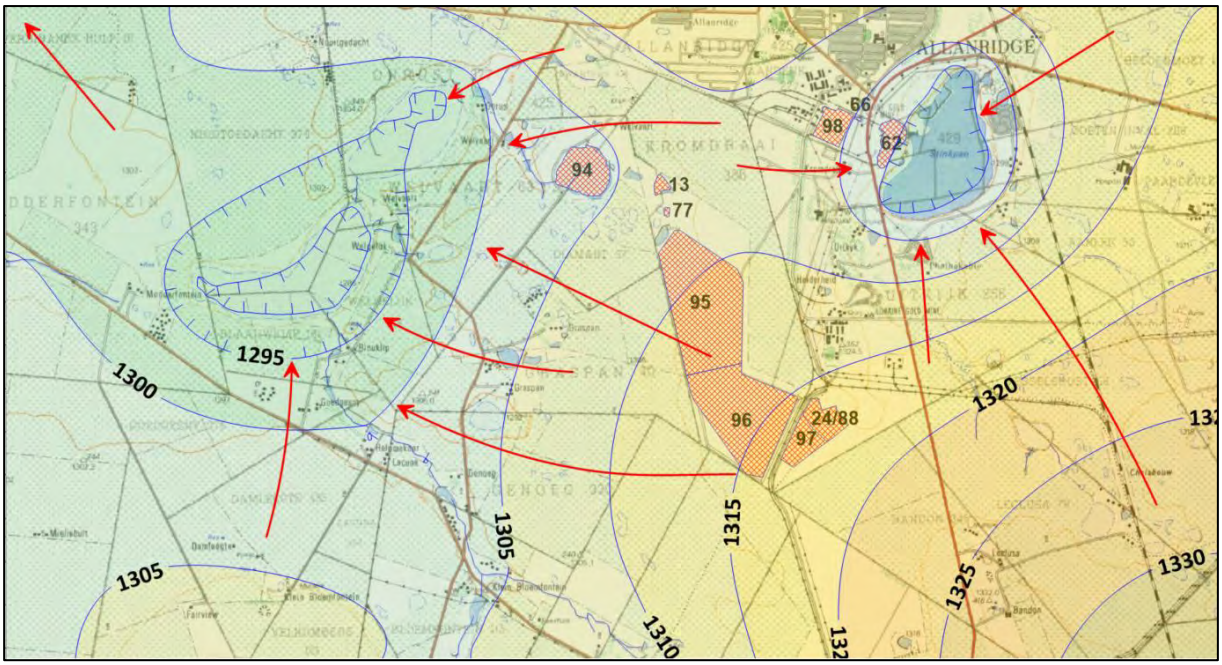


Figure 9-2 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows.

9.2.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes

The simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes are depicted in Figure 9-3. From this figure it is evident that the sulphate migrates to the northwest towards Swart Pan from the Target TSF Complex. It further migrates from the Target TSF Complex to the west towards the unnamed pan. It also migrates from the Target TSF Complex to the east towards the Stink Pan in the east. The plume is also migrating from the Swart Pan to the west towards the unnamed pan in the west. The minor sources of Harmony to the south

namely Lorraine 1 Old Waste Rock Dump, Million Gallon Dam and Target 3 Sewage Treatment Plant migrate towards the Stink Pan towards the southeast.

In general, the correspondence between the simulated sulphate concentrations and the observed sulphate concentrations in the boreholes is good from a qualitative perspective. The map in general indicates that the simulated plumes overlap with areas of poorer observed water qualities. It is also evident from the map that in most cases where observed qualities seem unaffected that the model prediction agrees. Concentration outliers are observed at boreholes to the southwest of Stink Pan where boreholes A7 and BHVP1 shows higher sulphate concentrations as compared to the simulated. This is also observed at borehole BHVP2 to the northeast of the Stink Pan. It should be noted that only one observation is available for borehole A7 (see Appendix IV) and future monitoring may verify this elevated concentration. This elevated concentration may also be a remnant impact originating from the old Lorraine Gold Mine. The elevated sulphate concentration observed in borehole BHVP2 is probably attributable to some other source of contamination and not Harmony operations related. The same explanation may apply to explain the elevated concentration at borehole BHVP1.

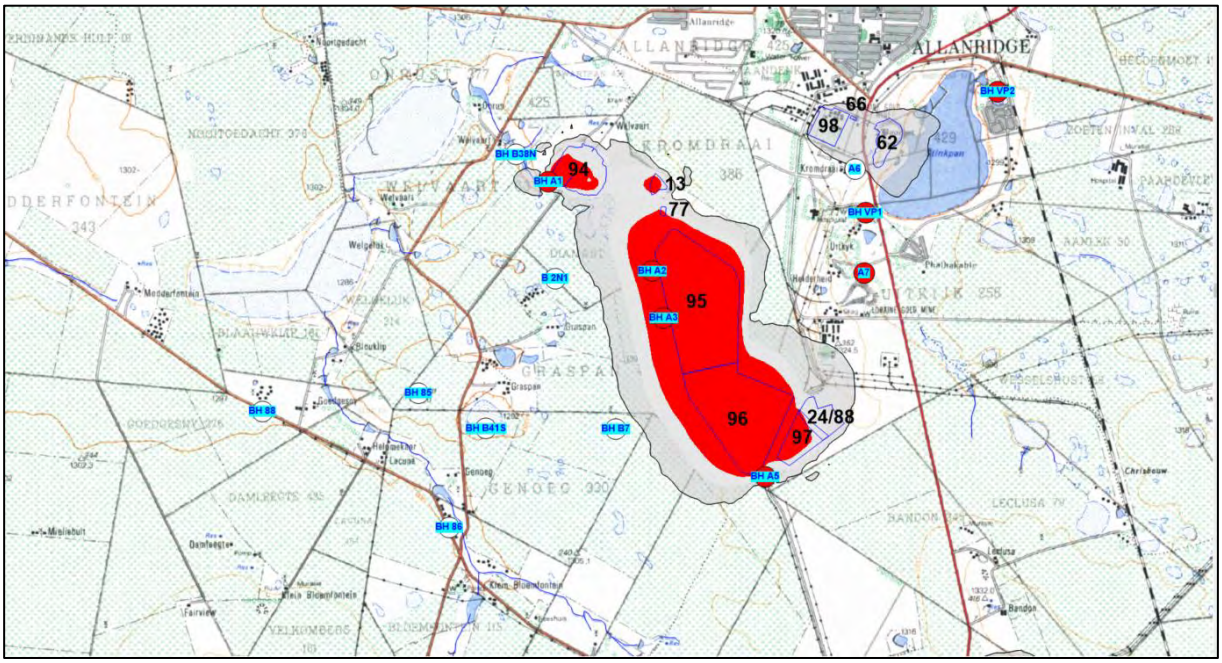


Figure 9-3 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers).

9.2.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR)

The mass loads from the sources to the groundwater pathway are depicted in Figure 9-4 and the cumulative mass loads from the sources to the groundwater pathway depicted in Figure 9-5.

The mass loads from the groundwater pathway to the receptors are depicted in Figure 9-6 and the cumulative mass loads from the groundwater pathway to the receptors depicted in Figure 9-7.

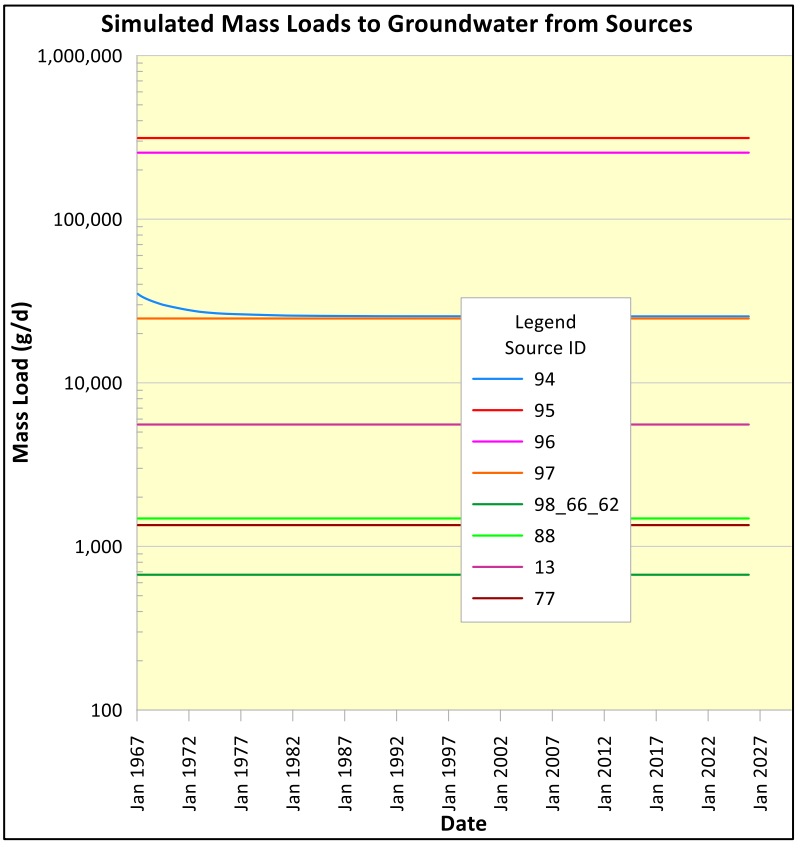


Figure 9-4 – Simulated mass loads to the groundwater pathway from sources.

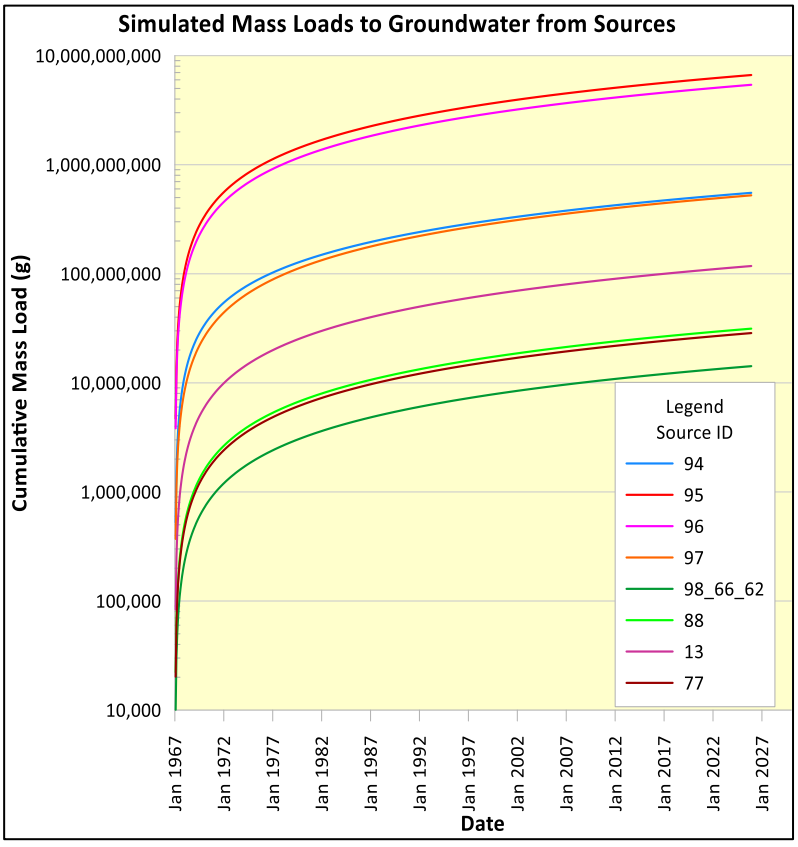


Figure 9-5 - Simulated cumulative mass loads to the groundwater pathway from sources.

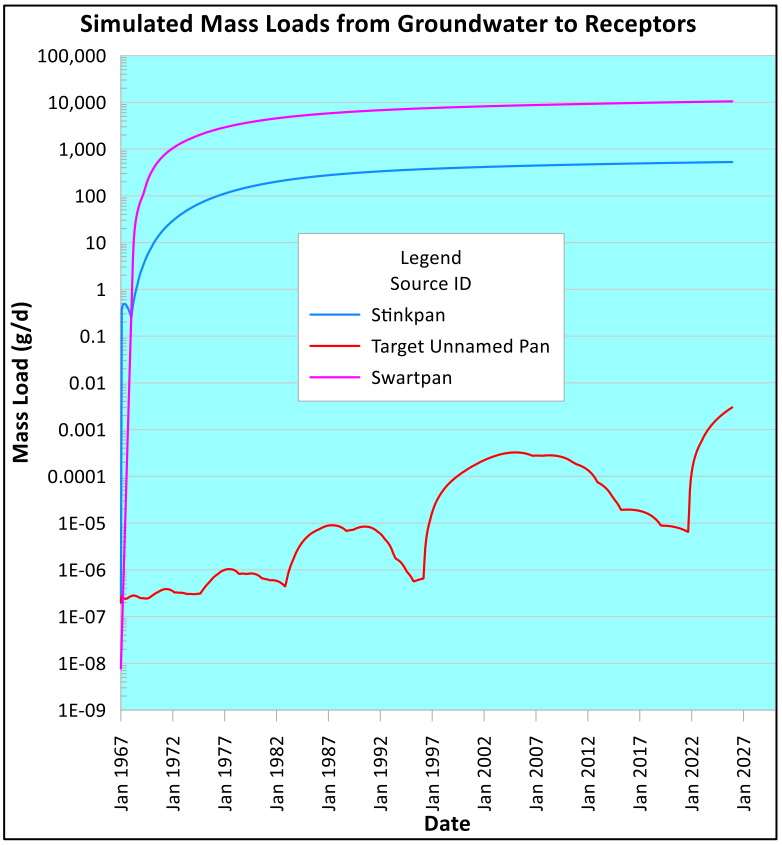


Figure 9-6 – Simulated mass loads from the groundwater pathway to receptors.

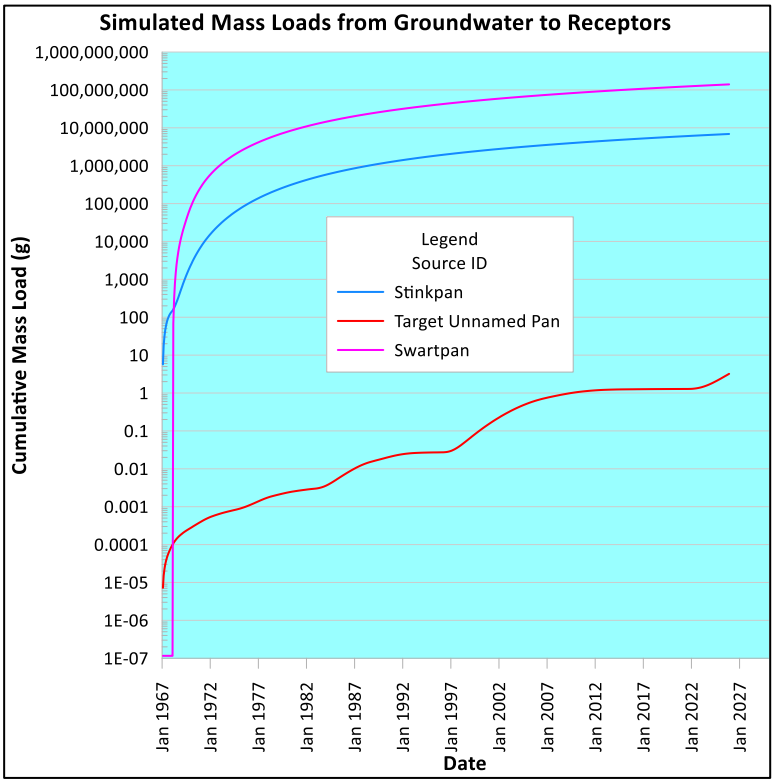


Figure 9-7 – Simulated cumulative mass loads from the groundwater pathway to receptors.

From the graphs presented the following is evident:

- Sources 95 (Target 1 TSF) and 96 (Target 2 TSF) contribute by far the most mass from sources to the groundwater pathway, about 568 kg/d.
- In comparison, the remainder of the sources contributes in total only about 59 kg/d to the groundwater pathway.
- This is reflected by the simulated sulphate plume in and around Target TSF1 and TSF2 as shown in Figure 9-3.
- The largest impact (although very small) from the groundwater pathway to a surface receptor is to the Swartpan where about 10 kg/d is reporting at the end of 2025.
- The impact on the Stinkpan is less than 1 kg/d.
- The impact on the unnamed pan in the west is zero.

9.3 Operations in the Freddies 9 Shaft and Tshepong Shaft Areas

9.3.1 Location

The Freddies 9 Shaft Operation (consisting of source ID's 27/30, 28 and 29) and Tshepong Shaft Operations (consisting of source ID's 21, 99, 100 and 101) are situated to the east and north of the town of Odendaalsrus and to the east of the unnamed drainage line draining to the northwest into the unnamed pan to the west of the Target Operation (Figure 9-8).

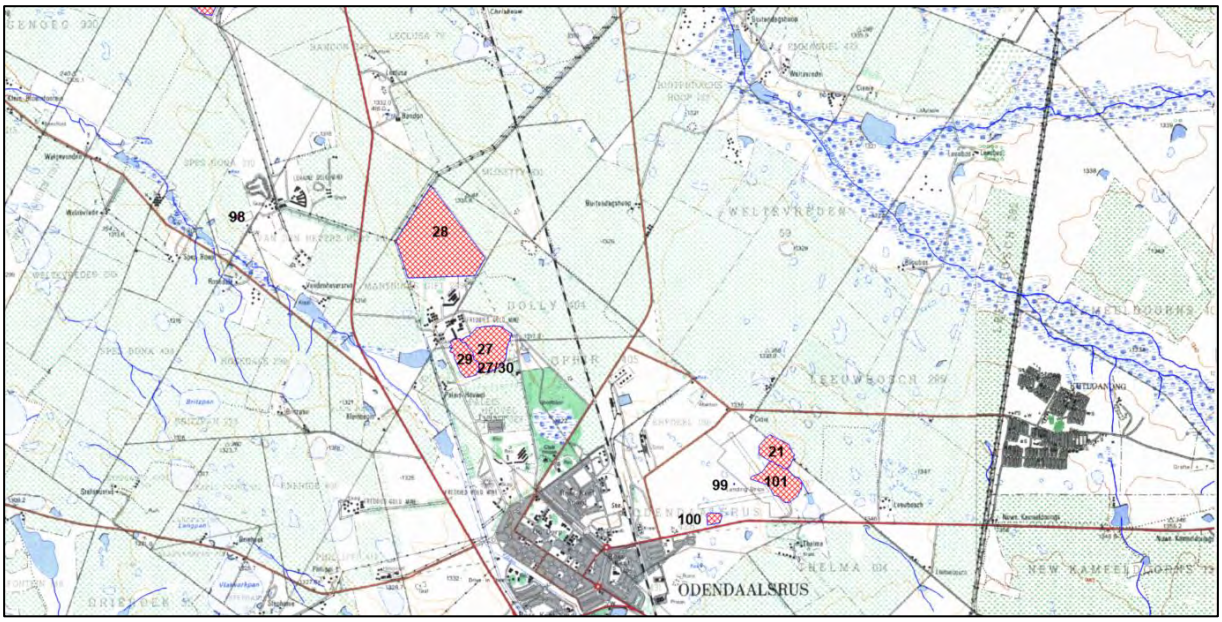


Figure 9-8 – Location of the Harmony Free State Freddie's 9 Shaft Operation (consisting **of source ID's 27/30, 28 and 29) and Tshepong Shaft Operations (consisting of source ID's 21, 99, 100 and 101)**. Sources are indicated by the red cross-hatched areas.

9.3.2 Sources

The sources depicted on Figure 9-8 are described in Table 9-2. The main sources in terms of size and contamination are Freddie's 9 Dam and Freddie's 9 Shaft Slimes Dam.

Table 9-2 – Freddie's 9 Shaft and Tshepong Shaft Operations source description.

No on Maps	ID	Source	Purpose/Description	SEEPAGE RATE (m/d)	CONCENTRATION (mg/l)	FEFLOW (mg/l*m/d)
	Freddies 9 #					
27	T_G12	Freddie's 9 Dam	Return Water Dam	0.000142274	544	0.077397
28	T_G11	Freddie's 9 Shaft Slimes dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
29	T_G8	Freddie's 9 Shaft Waste Rock Dump	Waste rock dump	4.74247E-05	96	0.004553
30	T_G13	Freddie's Return Water Dam	Return Water Dam	0.000142274	544	0.077397
	Tshepong Shaft					
21	H_G9	Duncan Dam	Process water dam	0.000142274	249	0.035426
99	H_G7	Tshepong Shaft Dam	Process water dam	0.000142274	1000	0.142274
100	H_G8	Tshepong Stormwater Dam	Stormwater runoff	0.000142274	1000	0.142274
101	H_G23	Tshepong Waste Rock Dump	Waste rock dump	4.74247E-05	96	0.004553

9.3.3 Groundwater Elevation Contours and Flow Directions

The groundwater elevation contours and groundwater flow directions are depicted in Figure 9-9. The

regional groundwater flow follows the regional topography which is from southeast to northwest. Locally however, groundwater flow from the Freddie's Shaft 9 Operation is towards the west towards the unnamed drainage line draining to the northwest into the unnamed pan to the west of the Target Operation. Flow from the Tshepong Shaft Operation flow is towards the north/northeast to the Sand Spruit. From a groundwater flow point of view, these two drainage lines will form Receptors in the SPR analysis.

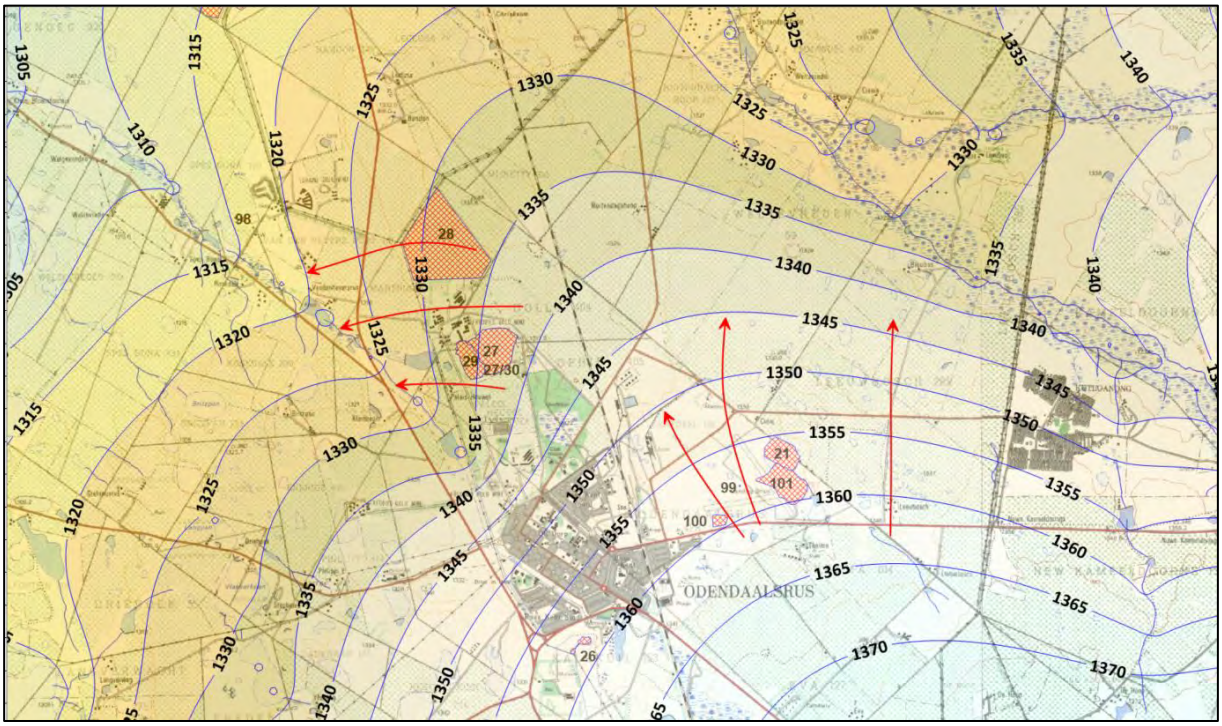


Figure 9-9 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows.

9.3.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes

The simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes are depicted in Figure 9-10. From this figure it is evident that the sulphate migrates from the Freddie's 9 Shaft facilities to the west and southwest towards the unnamed drainage line draining to the northwest into the unnamed pan to the west of the Target Operation. The plume is also migrating from the Tshepong Shaft operation towards the northeast towards the Sand Spruit.

There is too little observation borehole data available to ascertain whether the correspondence between the simulated sulphate concentrations and the observed sulphate concentrations in the boreholes is good from a qualitative perspective. The only available observation boreholes are at the Tshepong shaft operation namely boreholes BH198 and BH195. Borehole BH198 indicates that the simulated plume overlaps with areas of better observed water qualities and fits well. Borehole BH195 indicates to simulated concentrations lower than observed concentrations although the monitoring data indicates that this position is borderline between the two water classes (see Appendix IV).

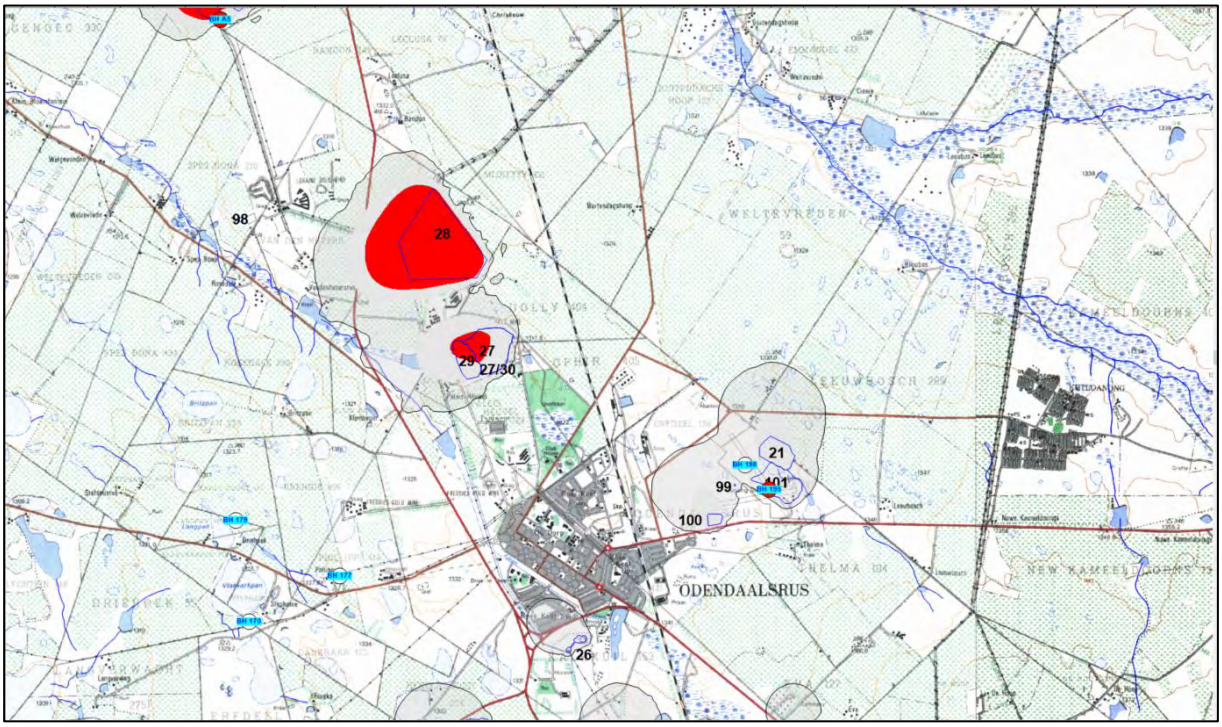


Figure 9-10 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers).

9.3.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR)

The mass loads from the sources to the groundwater pathway are depicted in Figure 9-11 and the cumulative mass loads from the sources to the groundwater pathway depicted in Figure 9-12.

The mass loads from the groundwater pathway to the receptors are depicted in Figure 9-13 and the cumulative mass loads from the groundwater pathway to the receptors depicted in Figure 9-14.

From the graphs presented the following is evident:

- Source 28 (Freddie's 9 Shaft Slimes dam) contributes by far the most mass from sources to the groundwater pathway, about 308 kg/d.
- In comparison, the remainder of the sources contributes in total only about 33 kg/d (Freddie's sources) and 13 kg/d (Tshepong sources) to the groundwater pathway.
- This is reflected by the simulated sulphate plume in and around Tshepong Shaft sources as shown in Figure 9-10.
- The largest impact (although very small) from the groundwater pathway to a surface receptor is to the Unnamed Drainage west of the Freddie's 9 Shaft facilities where about 0.5 kg/d is reporting at the end of 2025.

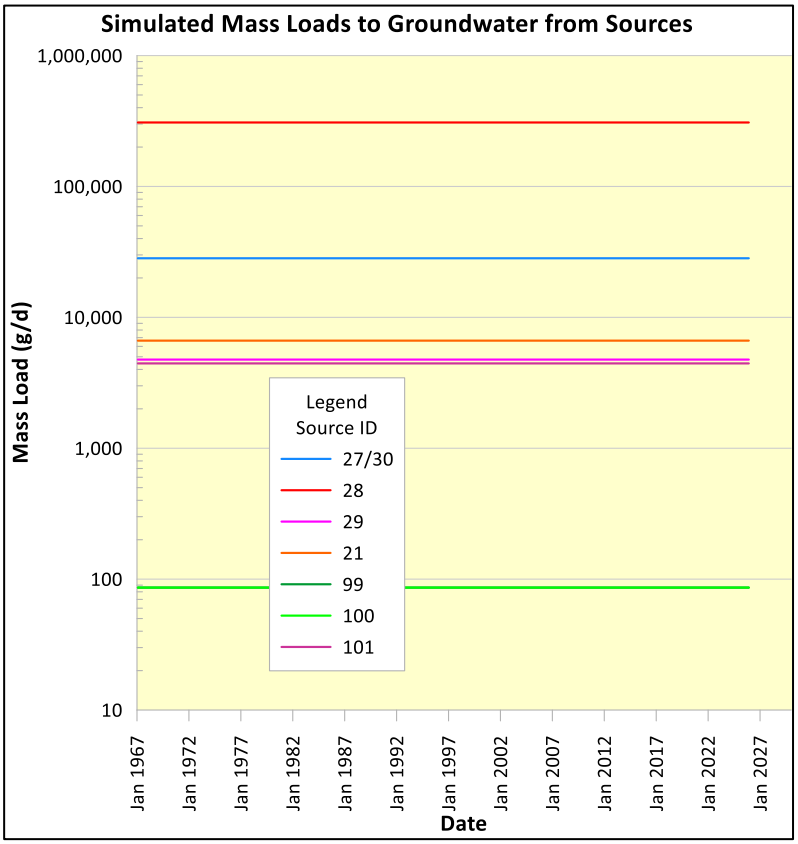


Figure 9-11 – Simulated mass loads to the groundwater pathway from sources.

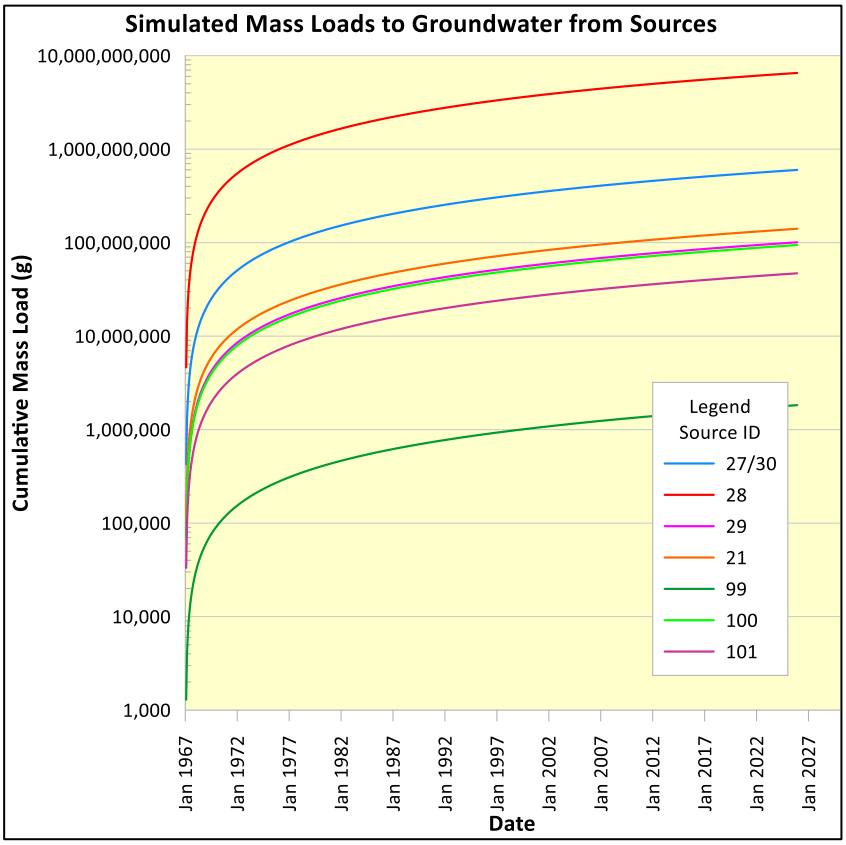


Figure 9-12 - Simulated cumulative mass loads to the groundwater pathway from sources.

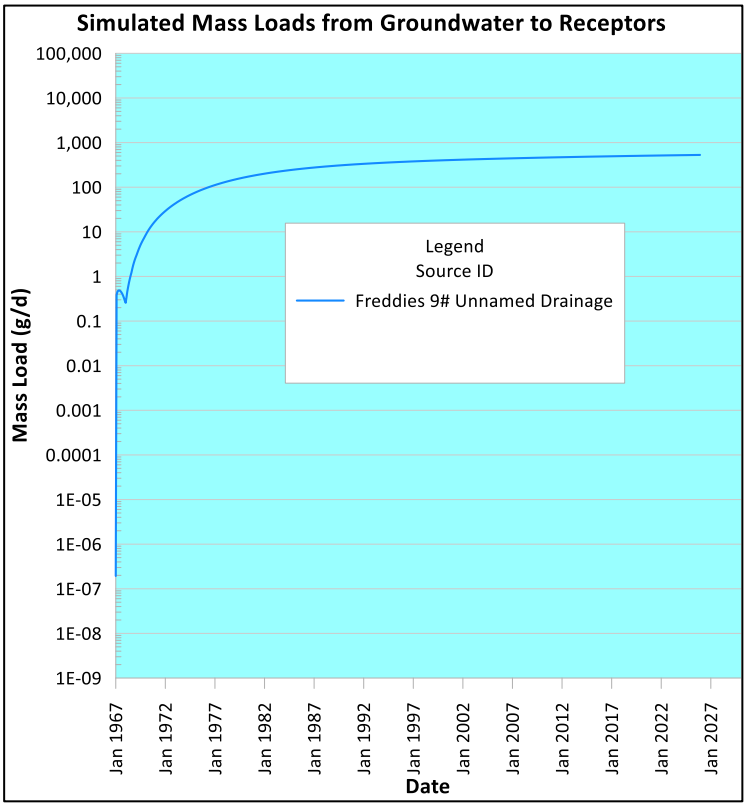


Figure 9-13 – Simulated mass loads from the groundwater pathway to receptors.

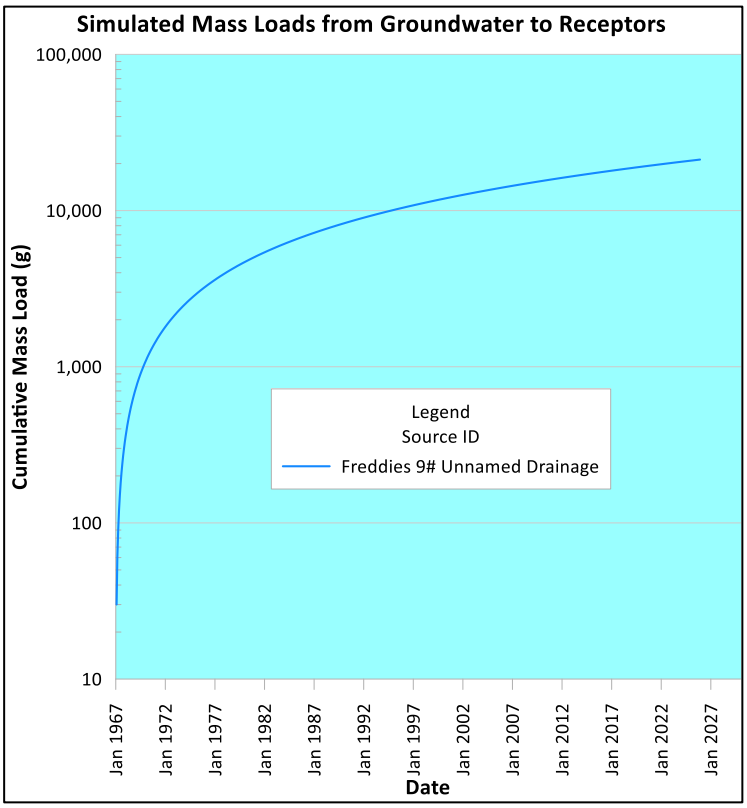


Figure 9-14 – Simulated cumulative mass loads from the groundwater pathway to receptors.

9.4 Operations in and around the Free State North (FSN) and ARM Dams

9.4.1 Location

The Harmony Free State North (FSN) and ARM Operations and Surrounding sources are situated southwest of the town of Odendaalsrus and to the northwest and north of the town of Welkom (Figure 9-15.

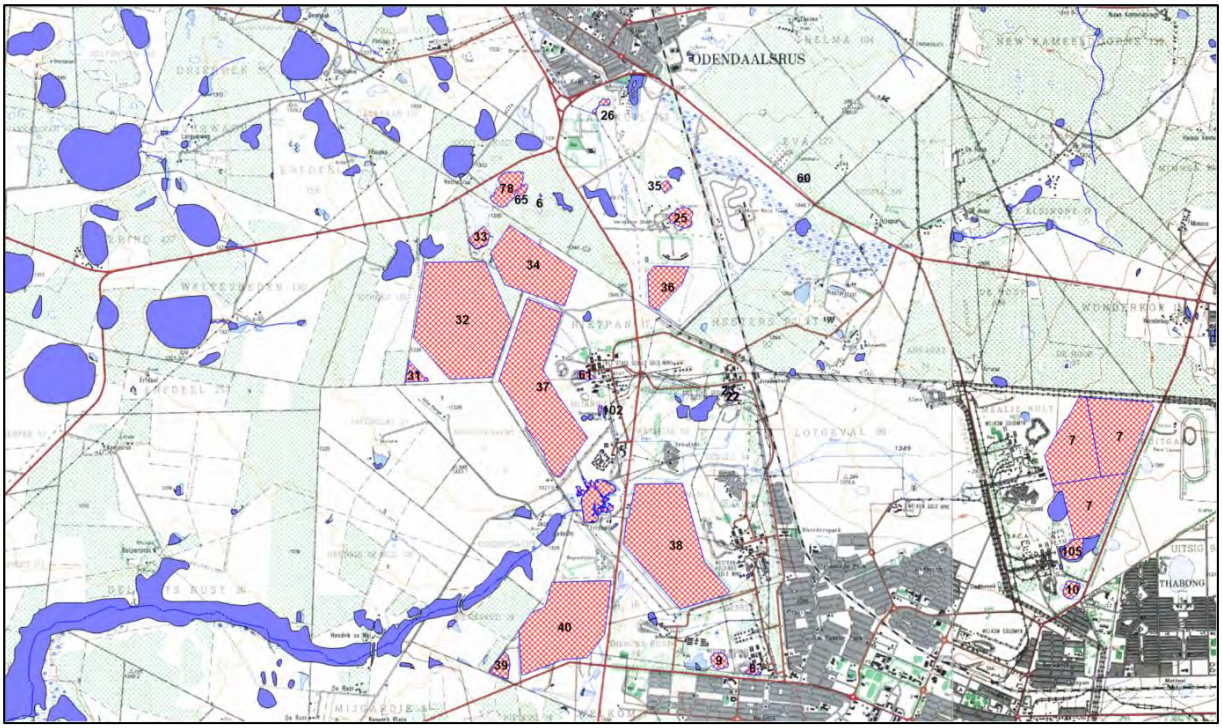


Figure 9-15 – Location of the Harmony Free State North (FSN) and ARM Operations and Surrounding sources. Sources are indicated by the red cross-hatched areas.

9.4.2 Sources

The sources depicted on Figure 9-15 are described in Table 9-3. The main sources in terms of size and contamination are the FSN TSF's and the ARM TSF's.

9.4.3 Groundwater Elevation Contours and Flow Directions

The groundwater elevation contours and groundwater flow directions are depicted in Figure 9-16. The regional groundwater flow follows the regional topography which is from southeast to northwest. Locally however, flow is to the west/southwest towards the Mahem Spruit which is west of the FSN TSF's. In the ARM TSF area flow to towards the southwest towards Witpan. These two groundwater depressions will form Receptors in the SPR analysis.

Table 9-3 – Harmony Free State North (FSN) and ARM Operations and Surrounding sources source description.

No on Maps	ID	Source	Purpose/Description	SEEPAGE RATE (m/d)	CONCENTRATION (mg/l)	FEFLOW (mg/l*m/d)
6	H_G11	3.7 Million Dam	Process water from Nyala Shaft before draining into Two Million Dam	0.000142274	1000	0.142274
25	T_G6	Freddie's 3 Shaft Waste Rock Dump	Waste rock dump (dormant)	4.74247E-05	96	0.004553
26	T_G7	Freddie's 6 Shaft Waste Rock Dump	Waste rock dump (dormant)	4.74247E-05	96	0.004553
31	H_G25	FSN 1 Return Water Dam	Return water dam	0.000142274	2285	0.325096
32	H_G24	FSN 1 Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
33	H_G27	FSN 2 Return Water Dam	Return water dam	0.000142274	1671	0.237740
34	H_G26	FSN 2 Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
35	H_G28	FSN 3A Slimes Dam Complex	Tailings storage facility (dormant)	0.000142274	1942	0.276296
36	H_G29	FSN 3B Slimes Dam Complex	Tailings storage facility (dormant)	0.000142274	1942	0.276296
37	H_G30	FSN 4 Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
38	H_G31	FSN 5 Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
39	H_G33	FSN 6 Return Water Dam	Return water dam	0.000142274	3293	0.468508
40	H_G32	FSN 6 Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
22	H_G20	Eland Shaft Waste Rock Dump	Waste rock dump (earmarked for backfilling)	4.74247E-05	96	0.004553
23	H_G13	Eland Shaft Water Dam	Process water dam	0.000142274	249	0.035426
60	H_G3	Koffer Dam	Process water dam	0.000142274	327	0.046524
61	H_G21	Kudu Shaft Waste Rock Dump	Waste rock dump (earmarked for backfilling)	4.74247E-05	96	0.004553
65	H_G10	Masons Vlei	Stormwater overflow from Nyala Shaft	0.000142274	213	0.030304
78	H_G22	Nyala Shaft Waste Rock Dump	Waste rock dump	4.74247E-05	96	0.004553
102	H_G12	Two Million Dam	Process water dam	0.000142274	1000	0.142274
52	C_G10	Harmony D-Dam	Return water dam	0.000142274	1526	0.217110
8	H_G18	ARM 6 Shaft Waste Rock Dump A - Unwashed	Waste rock dump (dormant)	4.74247E-05	96	0.004553
9	H_G19	ARM 6 Shaft Waste Rock Dump B - Washed	Waste rock dump (dormant)	4.74247E-05	96	0.004553
7	H_G34	ARM (Welkom) Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
10	HF1	ARM Vlei	Process water dam	0.000142274	241	0.034288
105	H_G35	Welkom Return Water Dam (ARM TSF RWD)	Return water dam	0.000142274	2376	0.338043

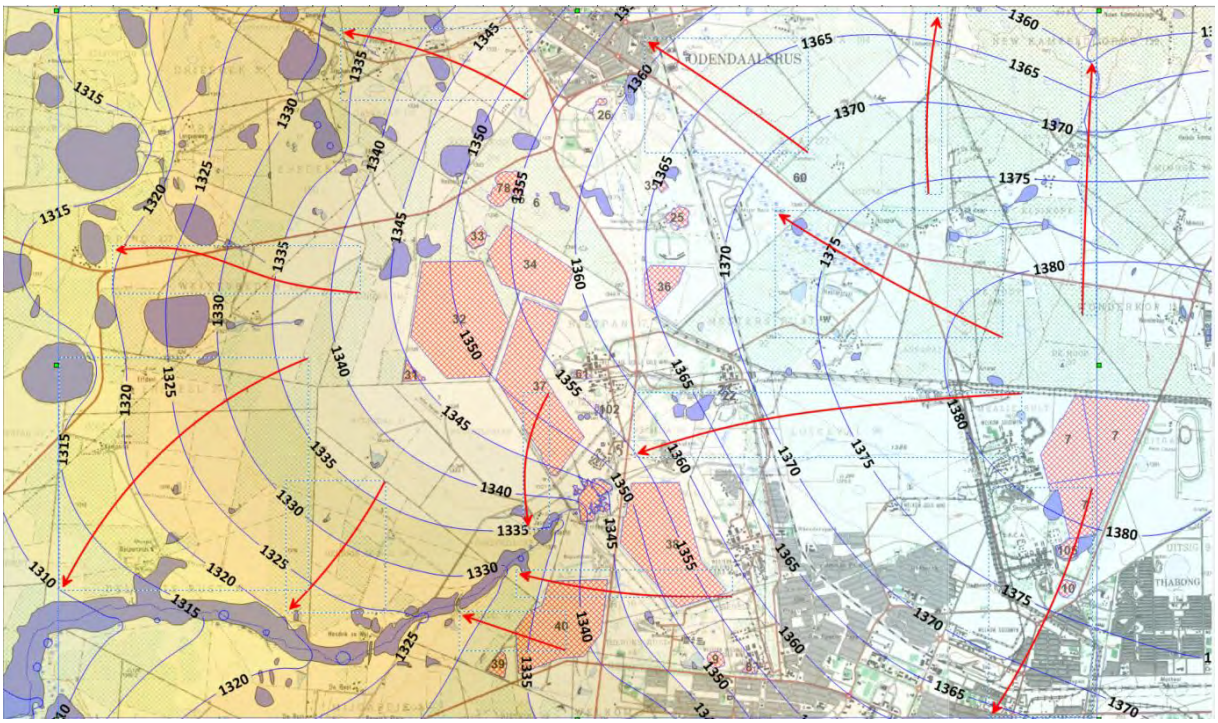


Figure 9-16 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows.

9.4.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes

The simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes are depicted in Figure 9-17. From this figure it is evident that the sulphate migrates to the west towards Mahem Spruit and to the northwest away from the FSN TSF's towards

the various surface pans in the west/northwest. The plume migrates towards the southwest away from the ARM TSF's towards Witpan in the southwest. The plume is also migrating from the Freddies no 3 and 6 WRD's and the FSN3A TSF towards the northeast towards the unnamed drainage in the northeast. The plume migrates to the west from the FSN3B TSF.

In general, the correspondence between the simulated sulphate concentrations and the observed sulphate concentrations in the boreholes is good from a qualitative perspective. The map in general indicates that the simulated plumes overlap with areas of poorer observed water qualities. It is also evident from the map that in most cases where observed qualities seem unaffected that the model prediction agrees.

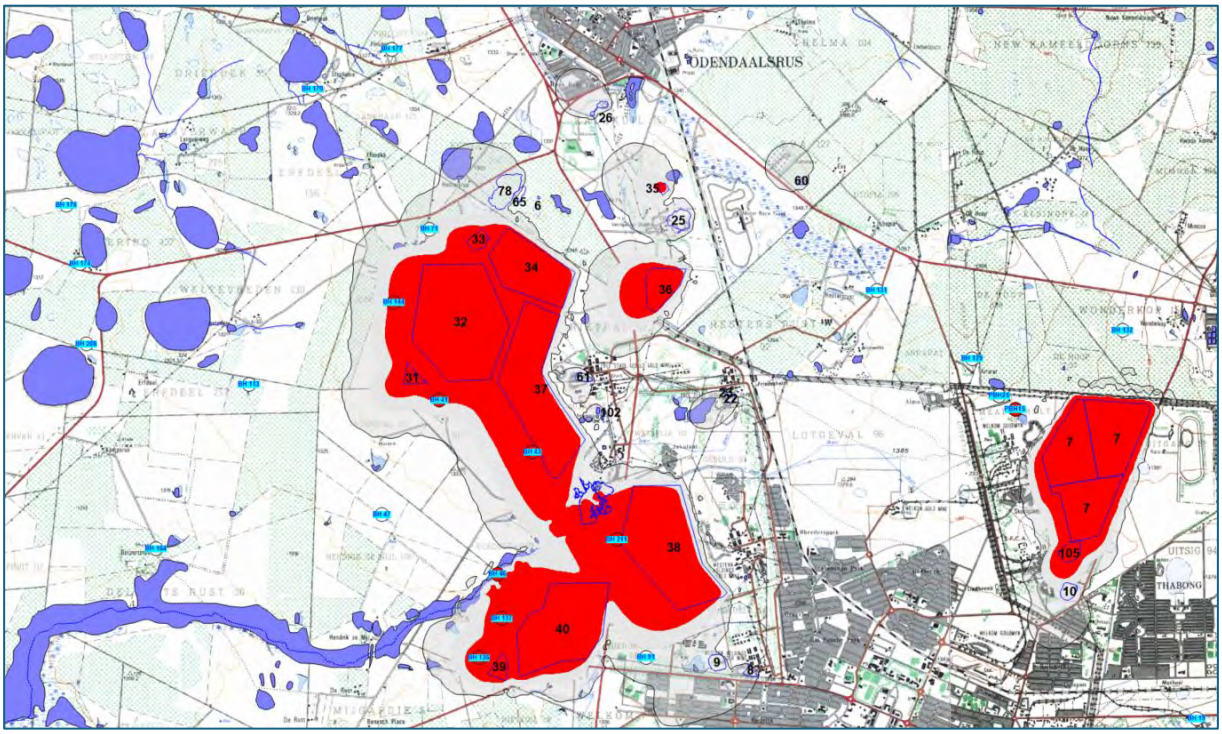


Figure 9-17 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers).

9.4.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR)

The mass loads and cumulative mass loads from the sources to the groundwater pathway are depicted in Figure 9-18 to Figure 9-23 for the FSN, ARM and other FSN sources.

The mass load from the groundwater pathway to the receptor (Mahem Spruit) is depicted in Figure 9-24 and the cumulative mass loads from the groundwater pathway to the receptors depicted in Figure 9-25.

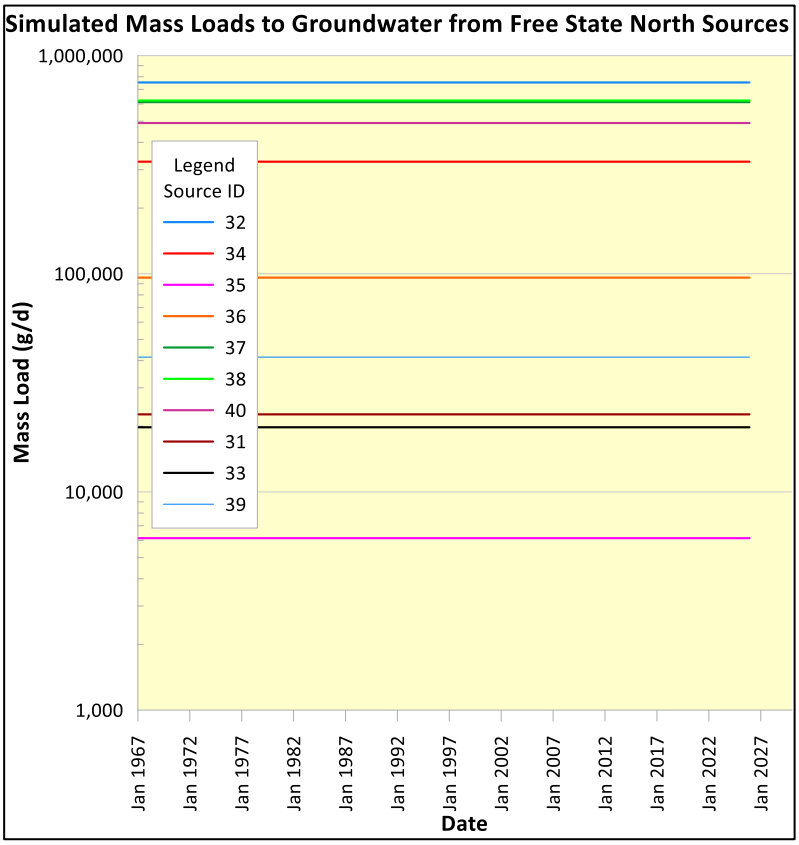


Figure 9-18 – Simulated mass loads to the groundwater pathway from FSN sources.

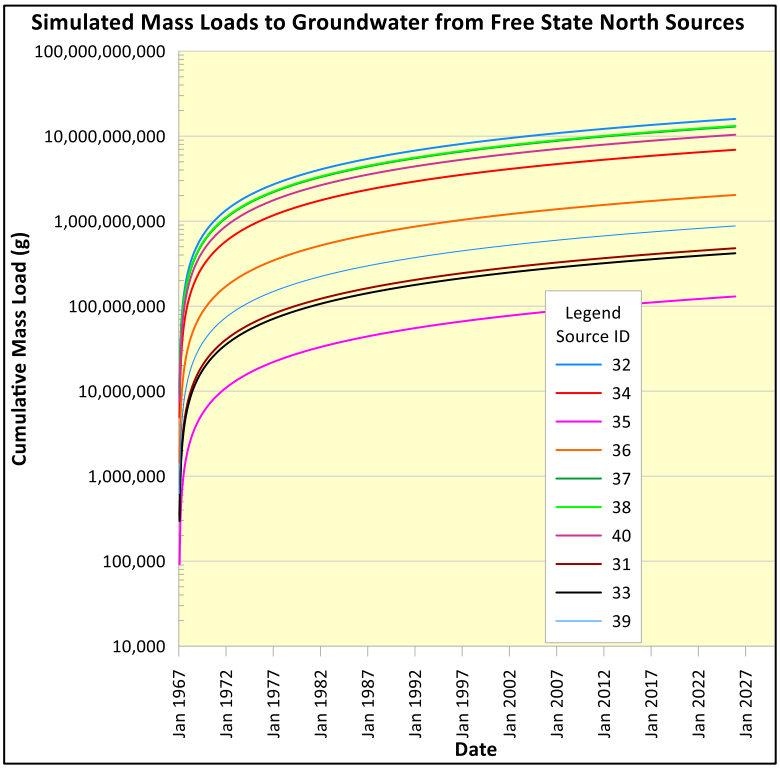


Figure 9-19 - Simulated cumulative mass loads to the groundwater pathway from FSN sources.

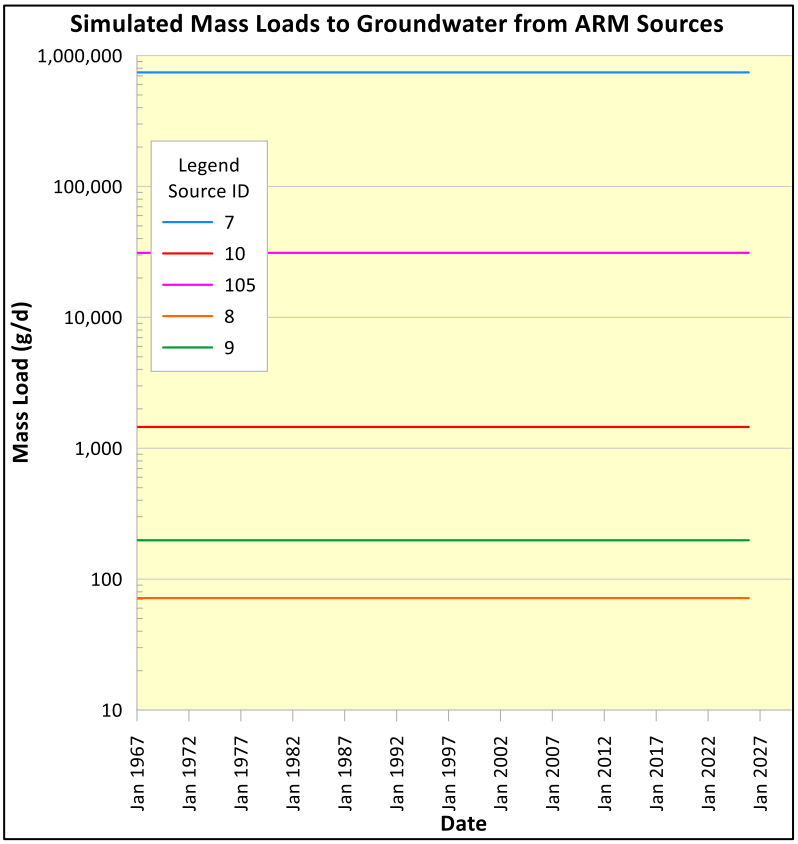


Figure 9-20 – Simulated mass loads to the groundwater pathway from ARM sources.

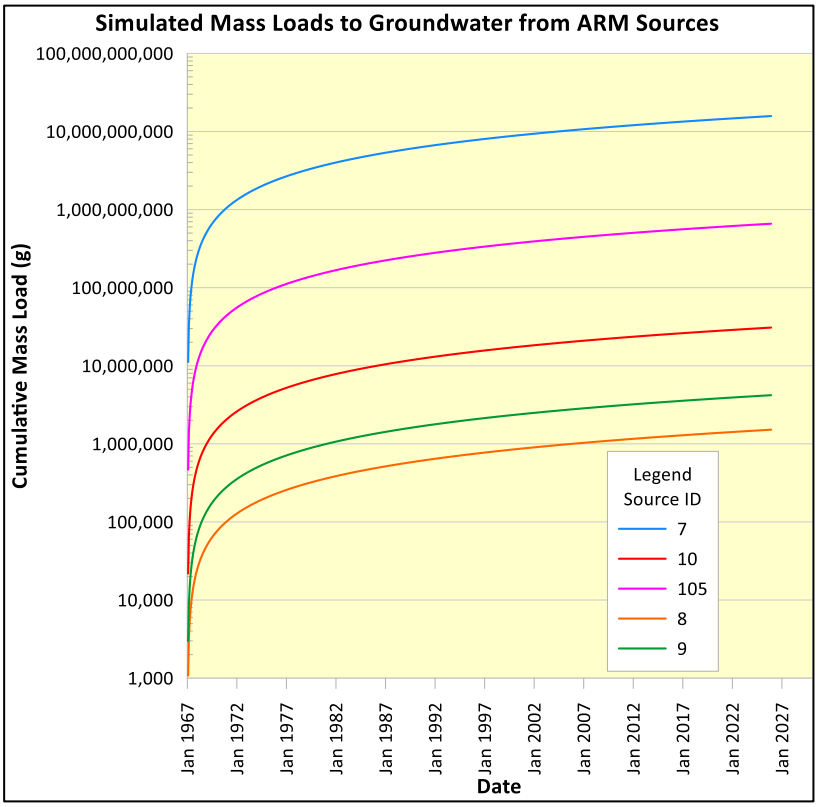


Figure 9-21 - Simulated cumulative mass loads to the groundwater pathway from ARM sources.

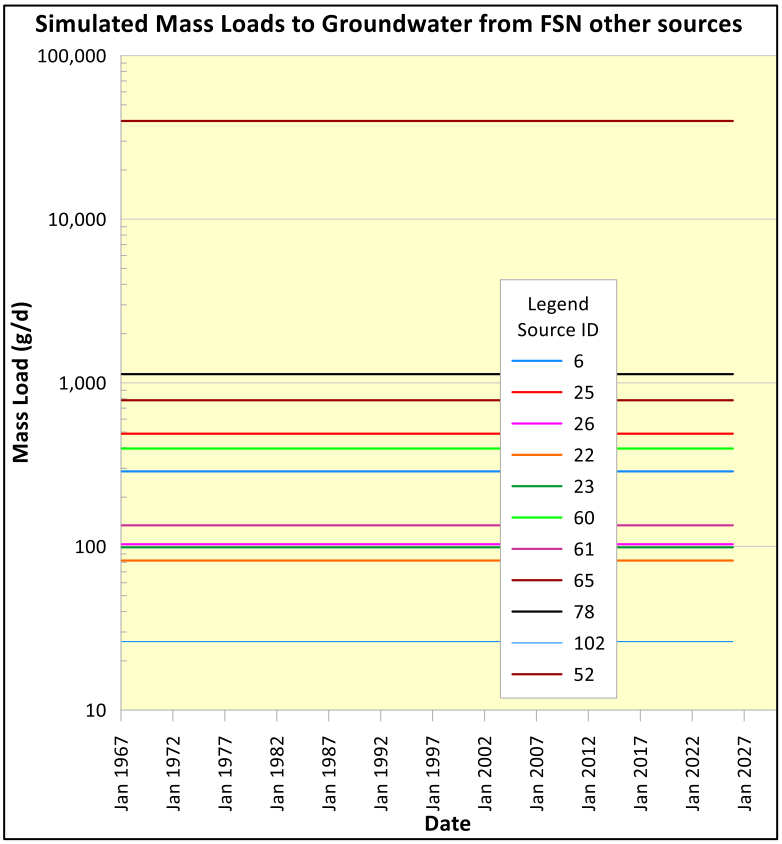


Figure 9-22 – Simulated mass loads to the groundwater pathway from FSN other sources.

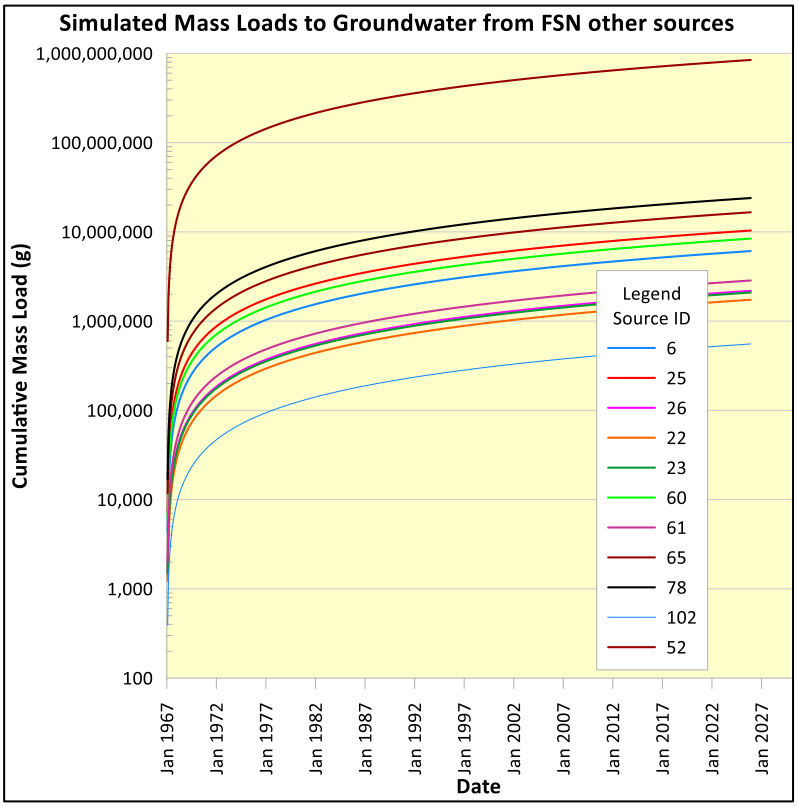


Figure 9-23 - Simulated cumulative mass loads to the groundwater pathway from FSN other sources.

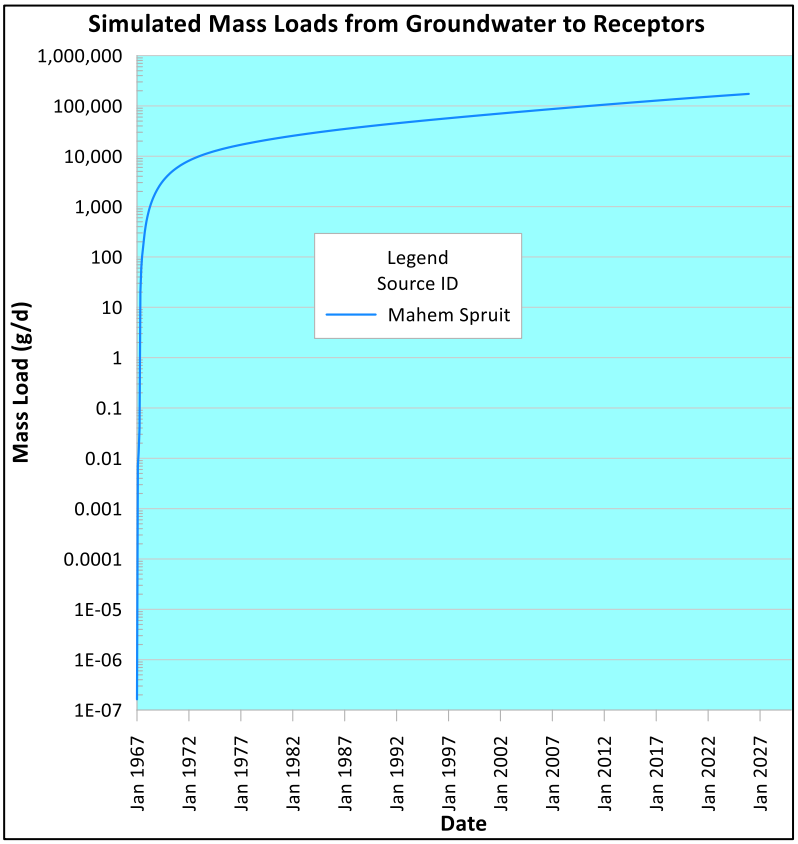


Figure 9-24 – Simulated mass loads from the groundwater pathway to receptors.

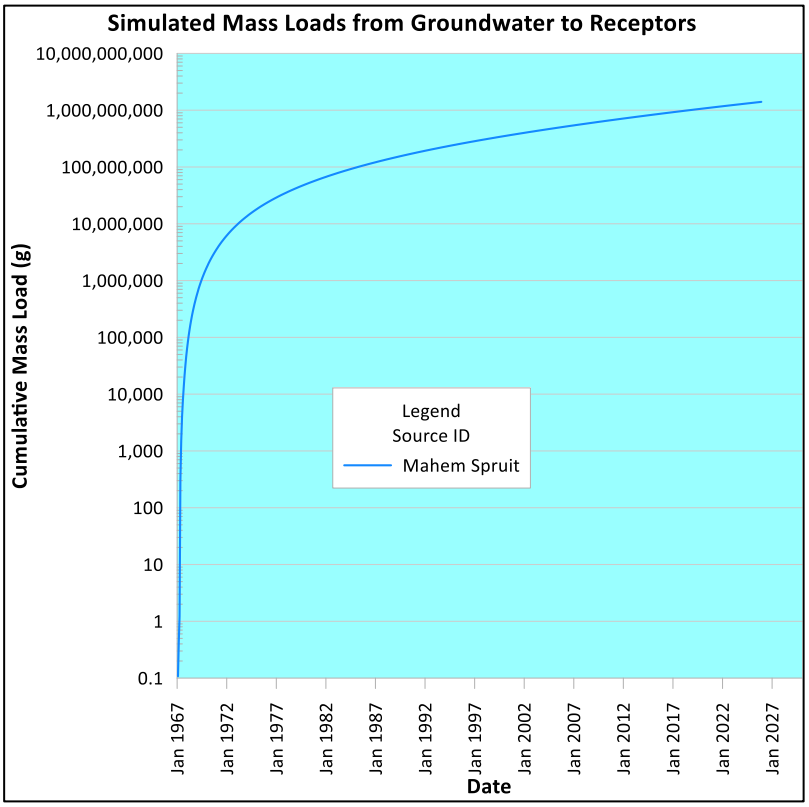


Figure 9-25 – Simulated cumulative mass loads from the groundwater pathway to receptors.

From the graphs presented the following is evident:

- Sources 32 (FSN1 Slimes Dam), 37 (FSN4 Slimes Dam), 38 (FSN5 Slimes Dam) and 34 FSN2 Slimes Dam) contribute by far the most mass from sources to the groundwater pathway, about 2314 kg/d.
- In comparison, the remainder of the FSN sources contributes in total only about 677 kg/d to the groundwater pathway.
- This is reflected by the simulated sulphate plume in and around the FSN sources as shown in Figure 9-17.
- The ARM (Welkom) Slimes Dam contributes the largest portion mass load of the ARM operation to the groundwater pathway, about 743 kg/d. The rest of the ARM sources (10, 105, 8 and 9) contributes in total 34 kg/d to the groundwater pathway.
- This is reflected by the simulated sulphate plume in and around the ARM sources as shown in Figure 9-17.
- The remainder of the FSN sources contribute only about 43 kg/d to the groundwater pathway.
- This is reflected by the simulated sulphate plume in and around the other FSN sources as shown in Figure 9-17.
- The largest impact from the groundwater pathway to a surface receptor is to the Mahem Spruit where about 173 kg/d is reporting at the end of 2025.

9.5 St. Helena Operations

9.5.1 Location

The St. Helena Operations are situated southwest of the town of Welkom and to the south of Toronto and Flamingo Pans as depicted on Figure 9-26.

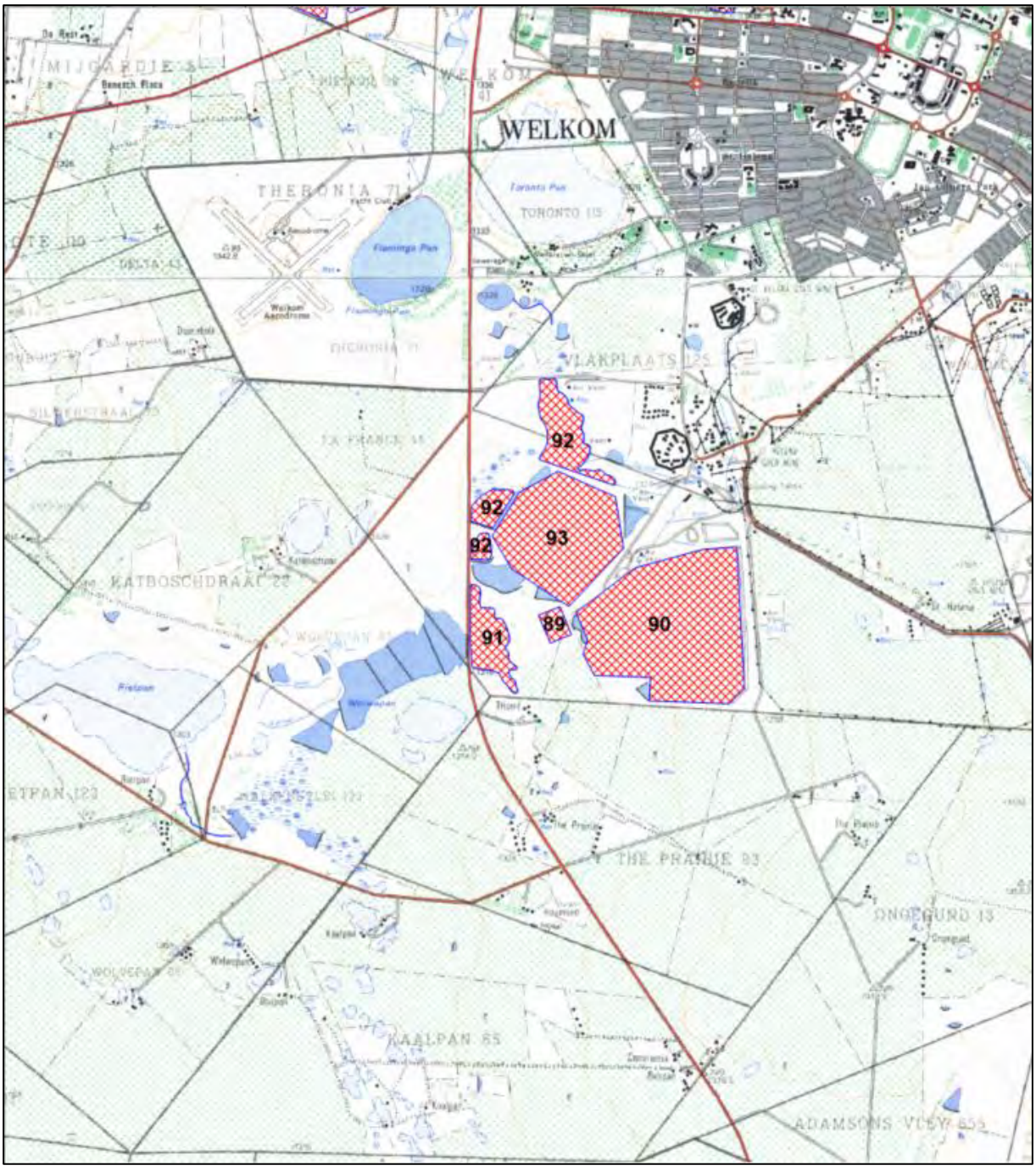


Figure 9-26 – Location of the Harmony Free State St. Helena Operation. Sources are indicated by the red cross-hatched areas.

9.5.2 Sources

The sources depicted on Figure 9-26 are described in Table 9-4. The main sources in terms of size and contamination are the St Helena 1,2,3 Slimes Dam Complex and the St. Helena 4 Slimes Dam.

Table 9-4 – St. Helena Operations source description.

No on Maps	ID	Source	Purpose/Description	SEEPAGE RATE (m/d)	CONCENTRATION (mg/l)	FEFLOW (mg/l*m/d)
89	S_G15	St Helena 1,2,3 Return Water Dam	Return water dam	0.000142274	1526	0.217110
90	S_G12	St Helena 1,2,3 Slimes Dam Complex	Tailings storage facility	0.000142274	1942	0.276296
91	S_G16	St Helena 1,2,3 Stormwater Dam	Return water dam	0.000142274	1526	0.217110
92	S_G14	St Helena 4 Return Water Dam	Return water dam	0.000142274	1526	0.217110
93	S_G13	St Helena 4 Slimes Dam	Tailings storage facilities (dormant)	0.000142274	1942	0.276296

9.5.3 Groundwater Elevation Contours and Flow Directions

The groundwater elevation contours and groundwater flow directions are depicted in Figure 9-27. The regional groundwater flow follows the regional topography which is from northeast to southwest. Locally however, three depressions in the groundwater elevation contours are visible from Figure 9-27. The first one is the Toronto Pan to the southwest of Welkom and the second one is the Rietpan southwest of St. Helena Operation. A smaller depression to the southwest of St. Helena is also present (Wolwepan). From a groundwater flow point of view, these three groundwater depressions may potentially form Receptors in the SPR analysis.

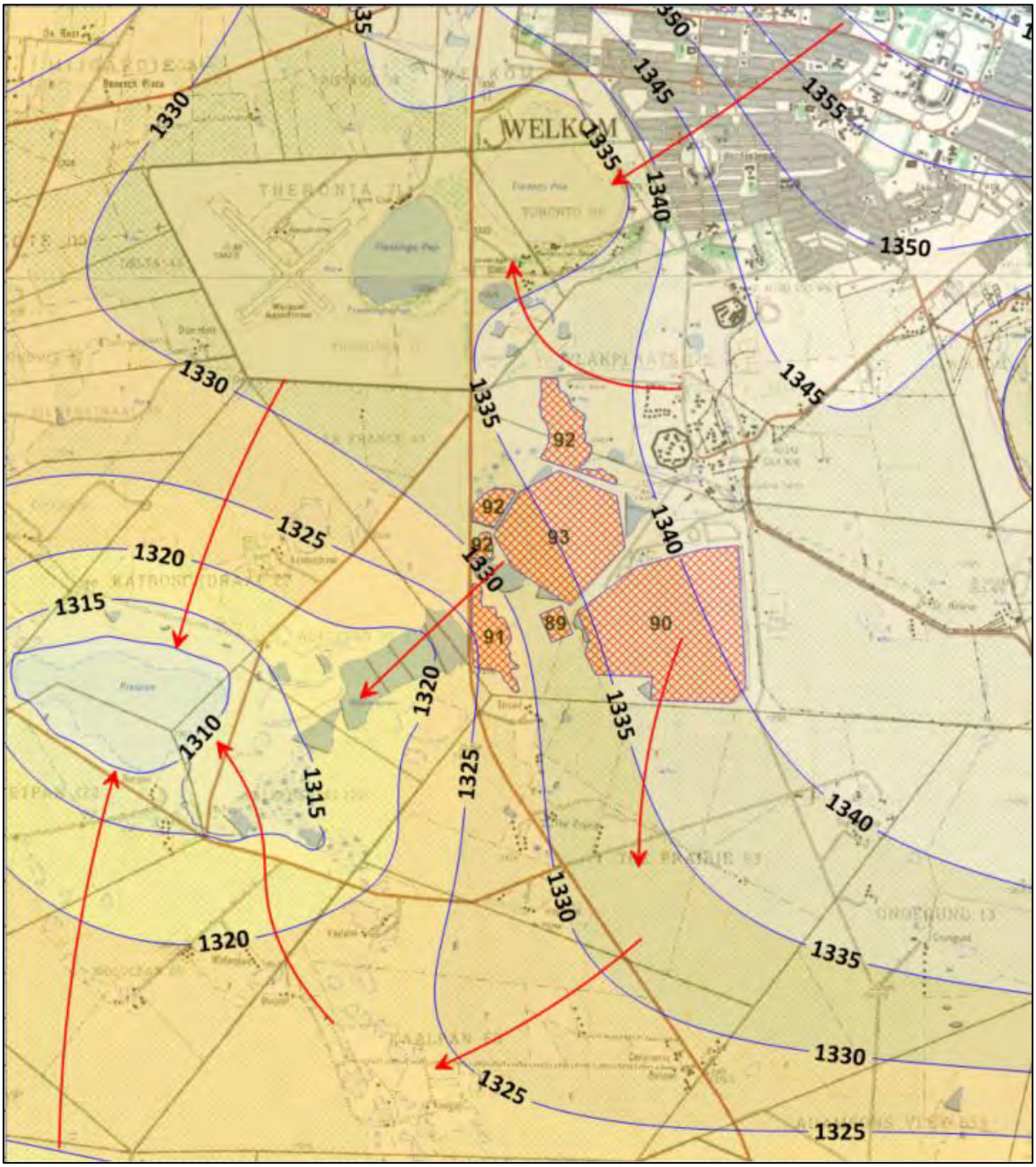


Figure 9-27 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows.

9.5.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes

The simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes are depicted in Figure 9-28. From this figure it is evident that the sulphate migrates to the north towards Toronto Pan and to the southwest towards Wolwepan/Rietpan from the St. Helena TSF Complex.

In general, the correspondence between the simulated sulphate concentrations and the observed sulphate concentrations in the boreholes is good from a qualitative perspective. The map in general

indicates that the simulated plumes overlap with areas of poorer observed water qualities. It is also evident from the map that in most cases where observed qualities seem unaffected that the model prediction agrees.

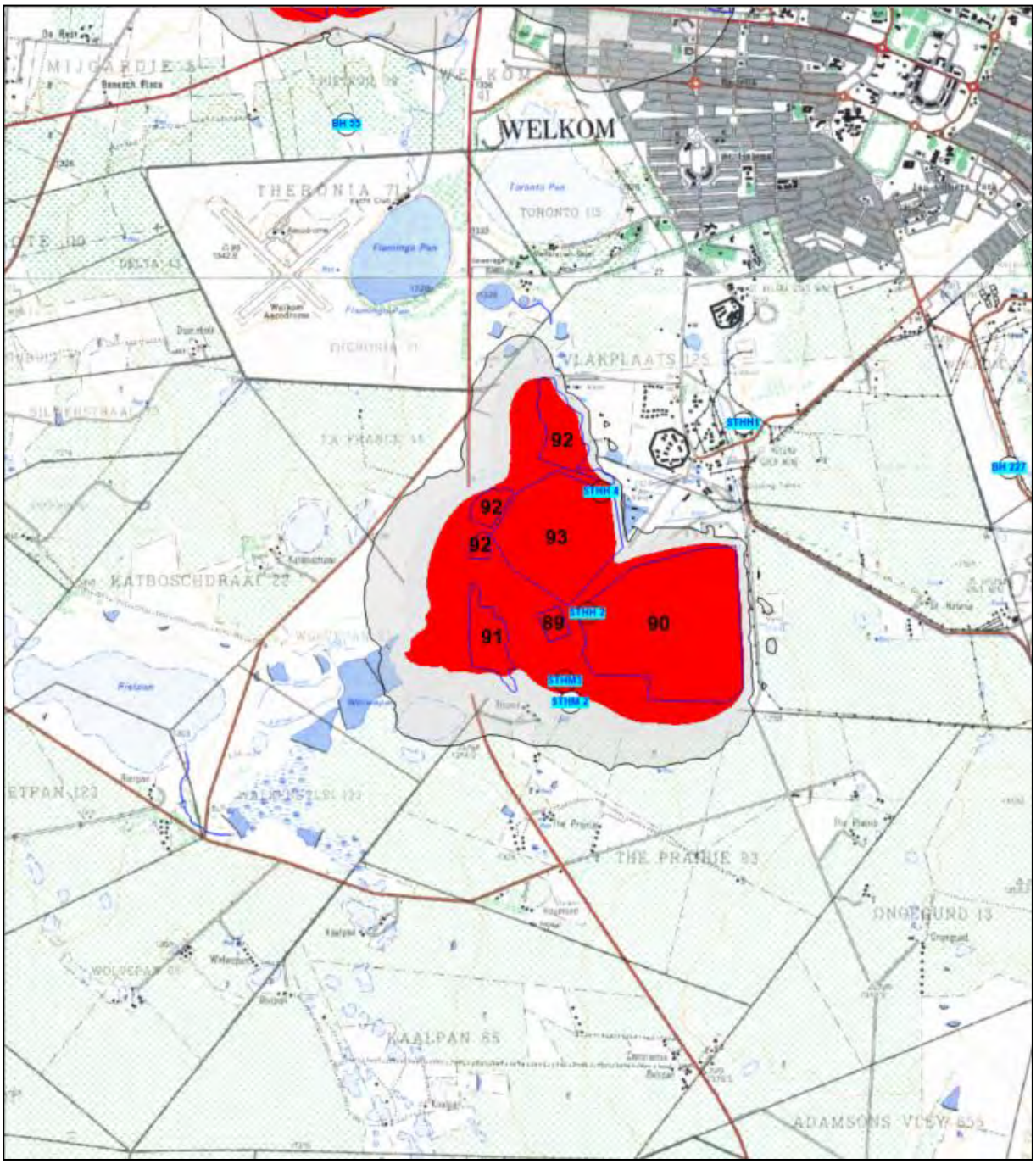


Figure 9-28 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers).

9.5.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR)

The mass loads from the sources to the groundwater pathway are depicted in Figure 9-29 and the cumulative mass loads from the sources to the groundwater pathway depicted in Figure 9-30.

The mass loads from the groundwater pathway to the receptors are depicted in Figure 9-31 and the cumulative mass loads from the groundwater pathway to the receptors depicted in Figure 9-32.

From the graphs presented the following is evident:

- Sources 90 (St Helena 1,2,3 Slimes Dam Complex) and 93 (St Helena 4 Slimes Dam) contribute by far the most mass from sources to the groundwater pathway, about 974 kg/d.
- In comparison, the remainder of the sources contributes in total about 210 kg/d to the groundwater pathway.
- This is reflected by the simulated sulphate plume in and around St. Helena TSF's as shown inFigure 9-28.
- The largest impact (although small) from the groundwater pathway to a surface receptor is to the Wolwepan where about 69 kg/d is reporting at the end of 2025.

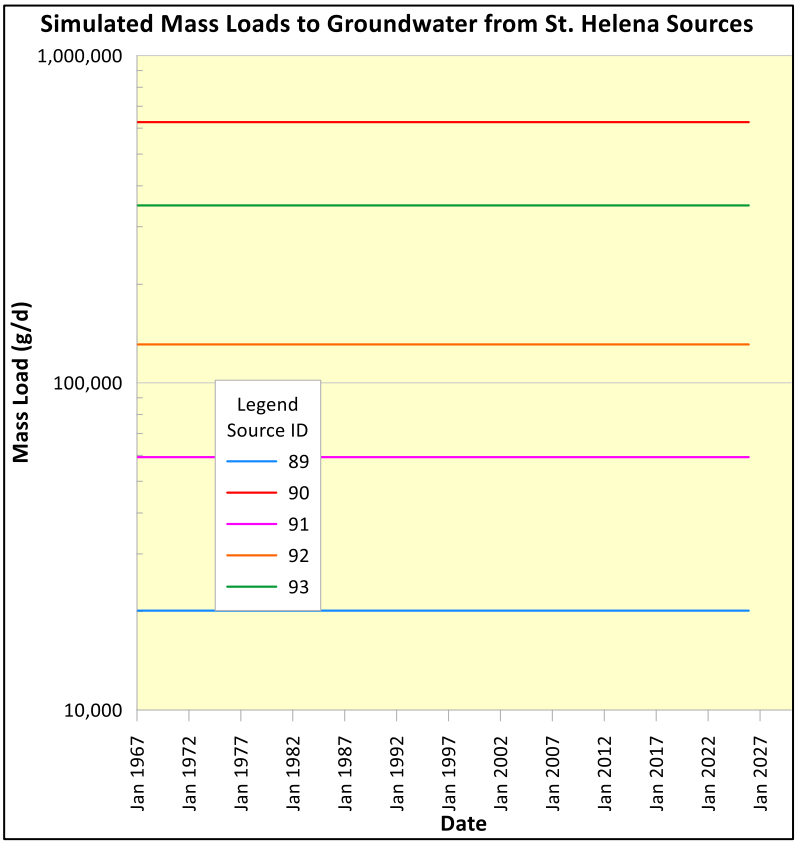


Figure 9-29 – Simulated mass loads to the groundwater pathway from sources.

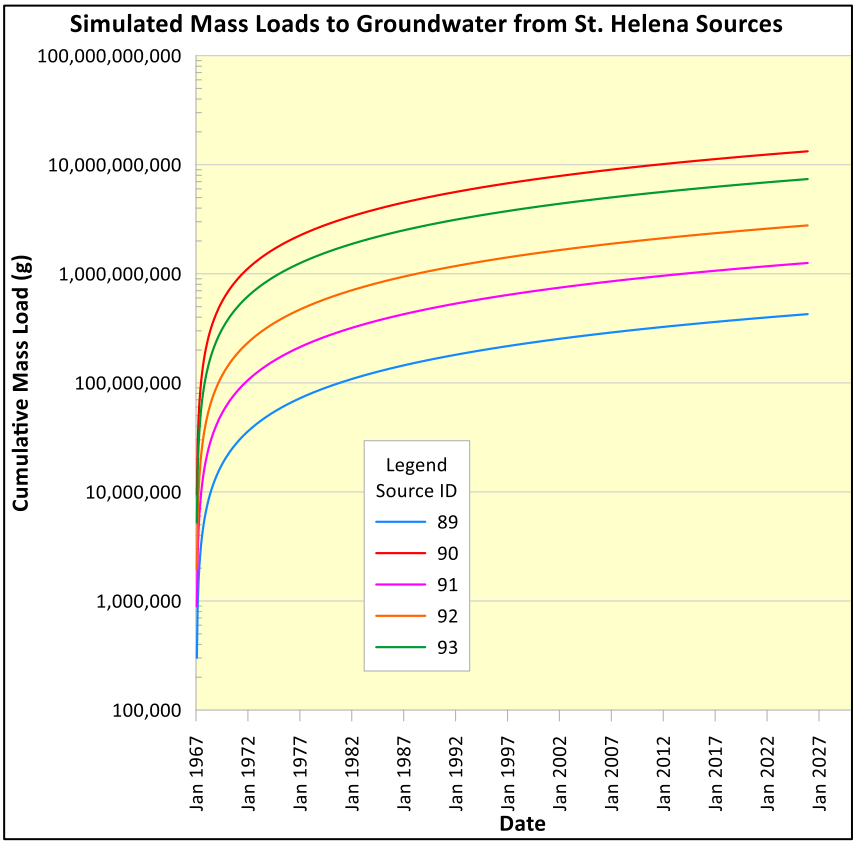


Figure 9-30 - Simulated cumulative mass loads to the groundwater pathway from sources.

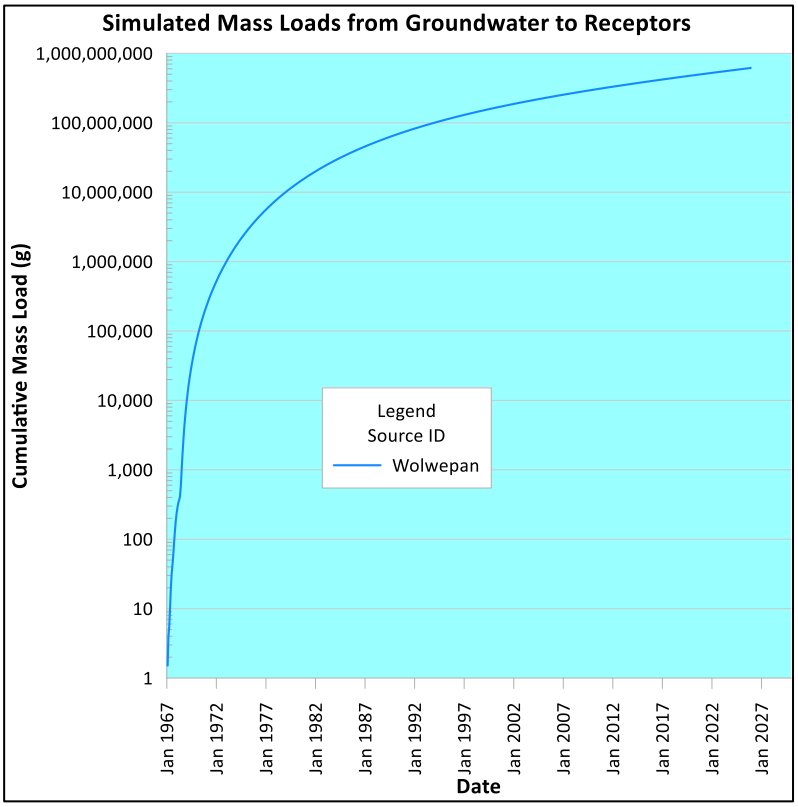


Figure 9-31 – Simulated mass loads from the groundwater pathway to receptors.

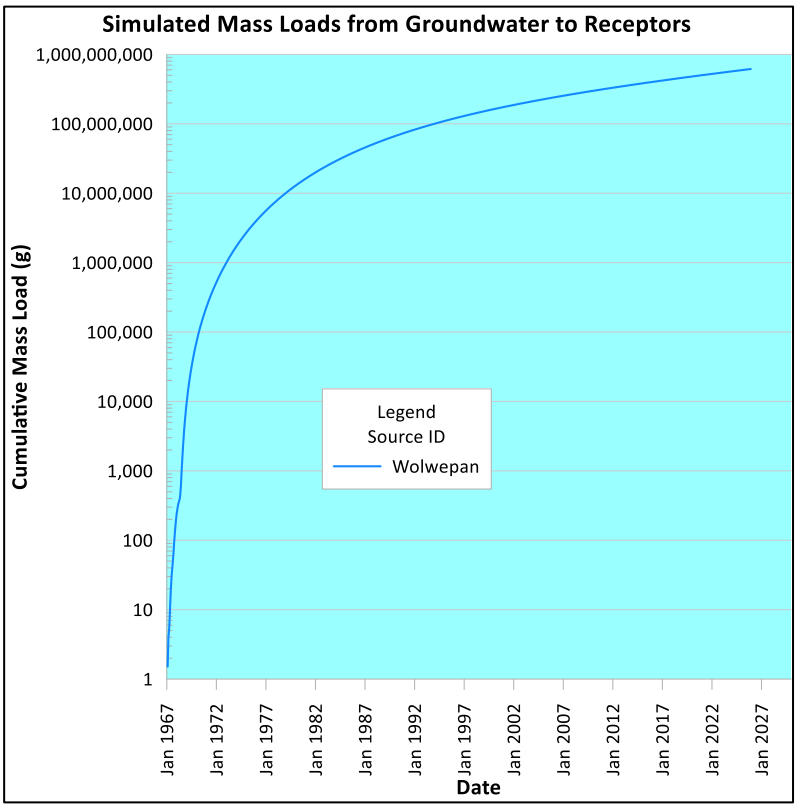


Figure 9-32 – Simulated cumulative mass loads from the groundwater pathway to receptors.

9.6 Operations in and around the Free State Operations (FSS) Dams

9.6.1 Location

The Harmony Free State Operation (FSS) are situated south of the town of Welkom and to the north of the Sand River (Figure 9-33).

9.6.2 Sources

The sources depicted on Figure 9-33 are described in Table 9-5. The main sources in terms of size and contamination are the FSS TSF's.

9.6.3 Groundwater Elevation Contours and Flow Directions

The groundwater elevation contours and groundwater flow directions are depicted in Figure 9-34. The regional groundwater flow follows the regional topography which is from north to south. Locally however, flow is to the Witpan depression which is situated west of the FSS TSF's. Flow to the south is towards the Sand River. These two drainages potentially will form Receptors in the SPR analysis.

Table 9-5 – Harmony Free State Operations (FSS) source description.

No on Maps	ID	Source	Purpose/Description	SEEPAGE RATE (m/d)	CONCENTRATION (mg/l)	FEFLOW (mg/l*m/d)
1	H-G45	Dam 13 Return Water Dam	Return water dam	0.000142274	642	0.091340
2	H_G42	12A Return Water Dam	Return water dam	0.000142274	1526	0.217110
3	H_G43	12B Return Water Dam	Return water dam	0.000142274	653	0.092905
4	H_G44	12C Return Water Dam	Return water dam	0.000142274	870	0.123778
11	H_G16	Bambanani East (President Steyn 3 Shaft) Waste Rock Dump	Waste rock dump (dormant - footprint remaining)	4.74247E-05	96	0.004553
12	H_G15	Bambanani West (President Steyn 3#) Waste Rock Dump	Waste rock dump (dormant - footprint remaining)	4.74247E-05	96	0.004553
41	H_G36	FSS1 Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
42	H_G37	FSS2 Slimes Dam	Tailings storage facility	0.000142274	1942	0.276296
43	C_G21	FSS3 Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
44	H_G39	FSS4 Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
45	C_G3	FSS5 Slimes Dam	Tailings storage facility	0.000142274	1942	0.276296
46	S_G17	FSS6 Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
47	H_G40	FSS7 Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
48	H_G41	FSS8 E&W Slime Dam Complex	Tailings storage facility (dormant)	0.000142274	1942	0.276296
53	H_G1	Harmony One Plant Surge Dam/Stormwater Dam	Storm water runoff and emergency dam	0.000142274	1000	0.142274
104	H_G5	Water Dam 33	Temporary storage of process water	0.000142274	1000	0.142274
106	H_G6	Wessel Pan	Excess water for reuse	0.000142274	2219	0.315706

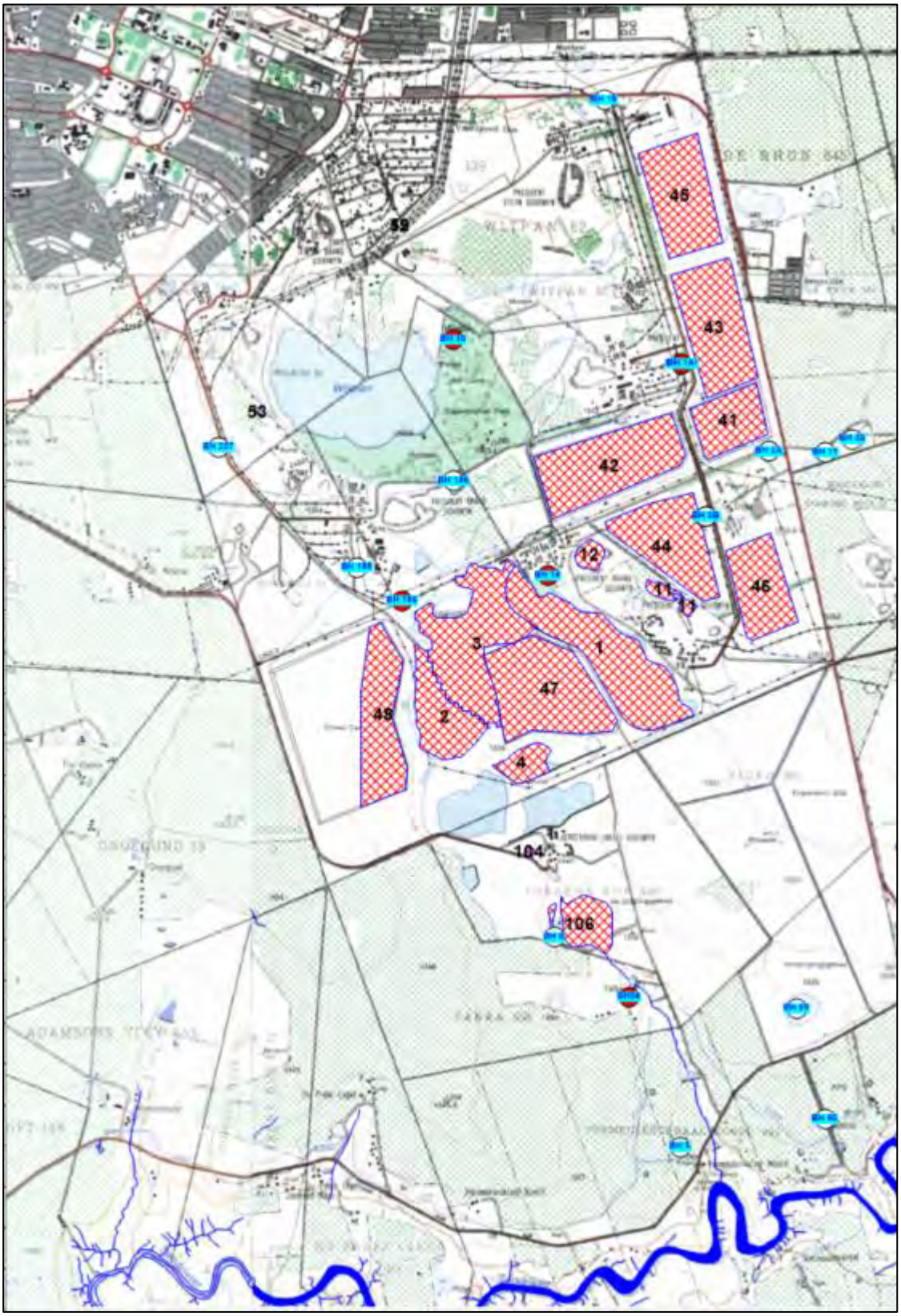


Figure 9-33 – Location of the Harmony Free State Operation (FSS). Sources are indicated by the red cross-hatched areas.

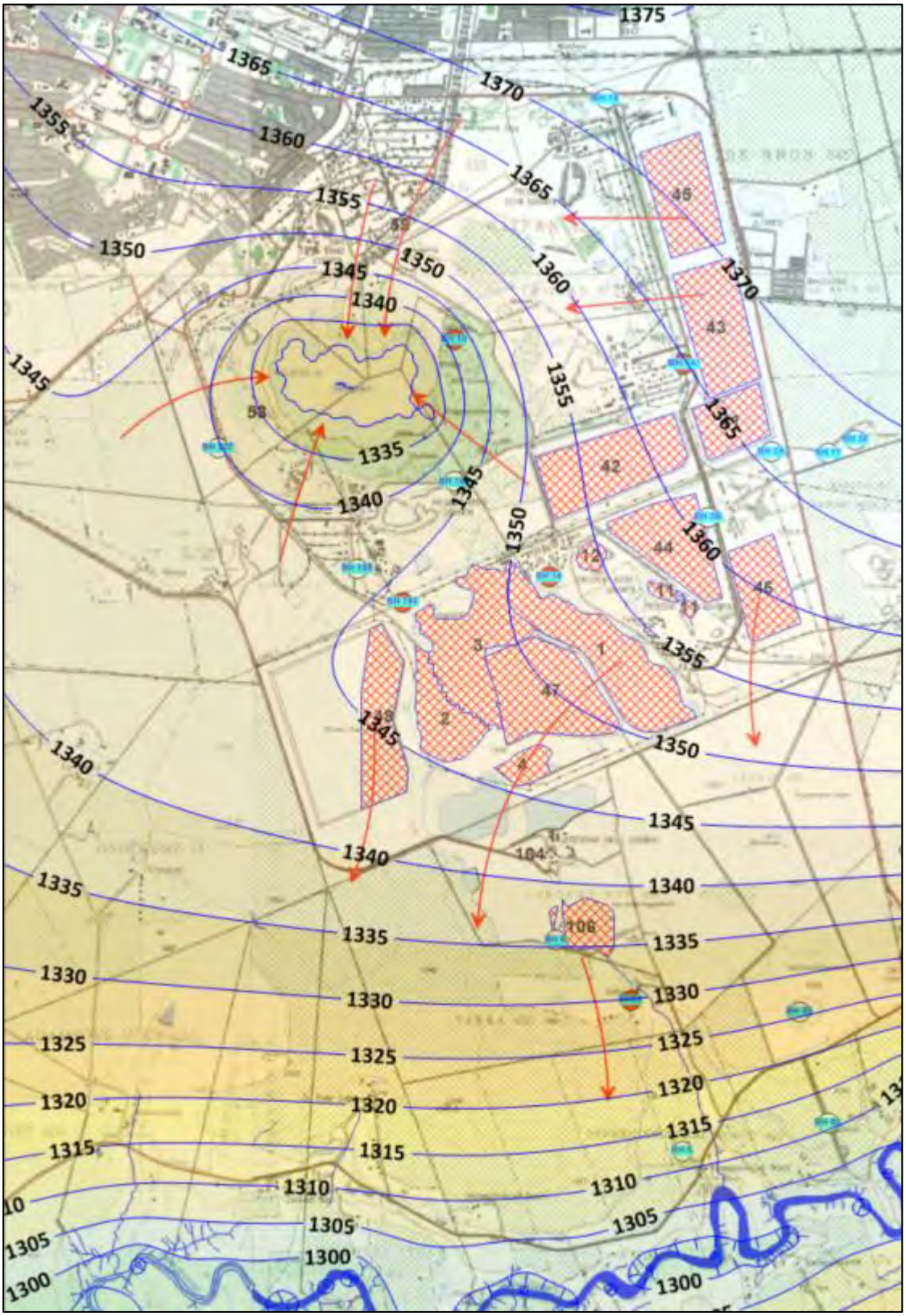


Figure 9-34 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows.

9.6.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes

The simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes are depicted in Figure 9-35. From this figure it is evident that the sulphate migrates to the west/northwest towards Witpan and to the south away from the FSS TSF's towards the Sand River in the south.

In general, the correspondence between the simulated sulphate concentrations and the observed sulphate concentrations in the boreholes is acceptable from a qualitative perspective. The map in general indicates that the simulated plumes overlap with areas of poorer observed water qualities. It is also evident from the map that in most cases where observed qualities seem unaffected that the model prediction agrees.

9.6.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR)

The mass loads and cumulative mass loads from the sources to the groundwater pathway are depicted in Figure 9-36 to Figure 9-39 for the FSS TSF's and other FSS sources.

The mass load from the groundwater pathway to the receptor (Witpan) is depicted in Figure 9-40 and the cumulative mass loads from the groundwater pathway to the receptor depicted in Figure 9-41.

From the graphs presented the following is evident:

- Sources 41-48 (FSS Slimes Dams) contribute by far the most mass from sources to the groundwater pathway, about 2121 kg/d.
- In comparison, the remainder of the FSS sources contributes in total about 563 kg/d to the groundwater pathway.
- This is reflected by the simulated sulphate plume in and around the FSS sources as shown in Figure 9-35.
- The largest impact from the groundwater pathway to a surface receptor is to the Witpan 9 kg/d is reporting at the end of 2025.

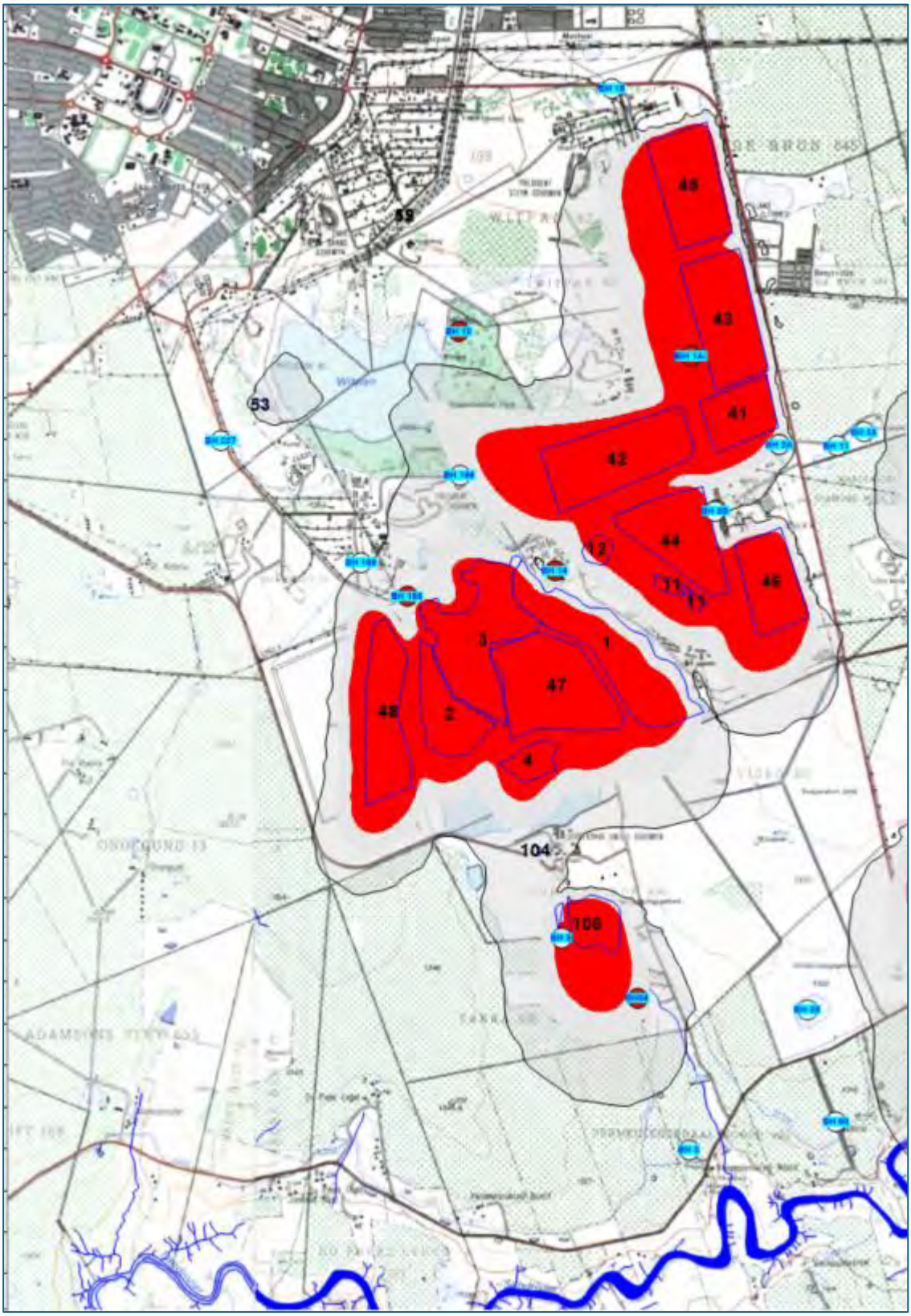


Figure 9-35 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers).

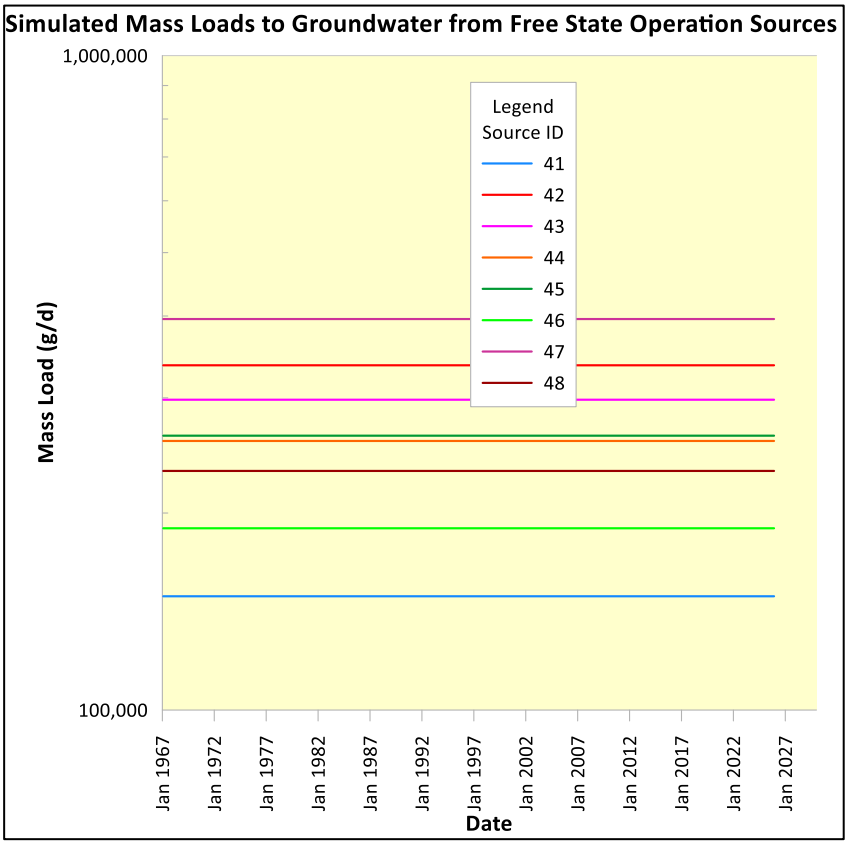


Figure 9-36 – Simulated mass loads to the groundwater pathway from FSS sources.

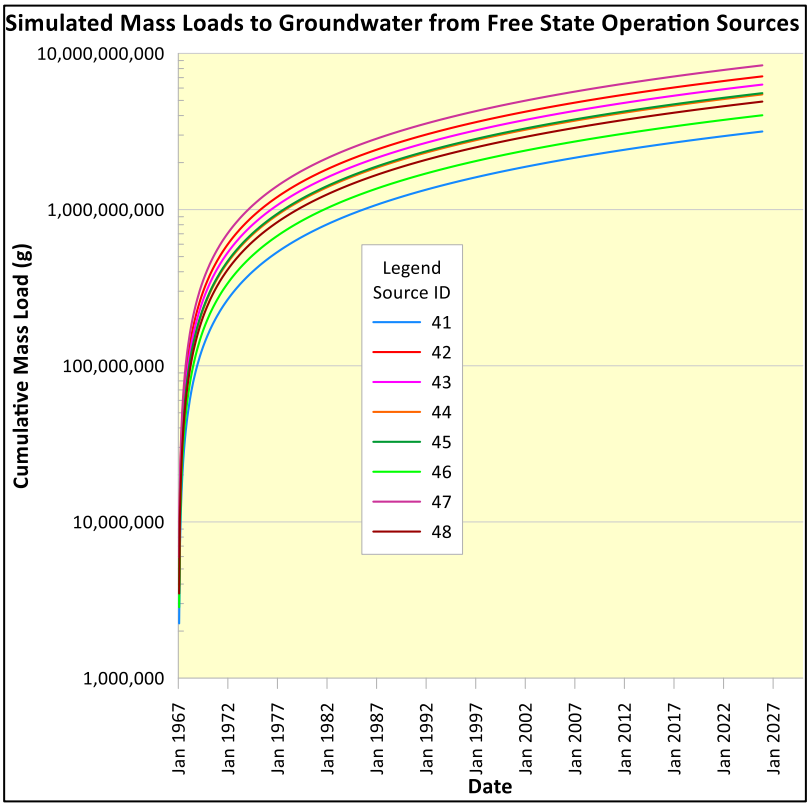


Figure 9-37 - Simulated cumulative mass loads to the groundwater pathway from FSS sources.

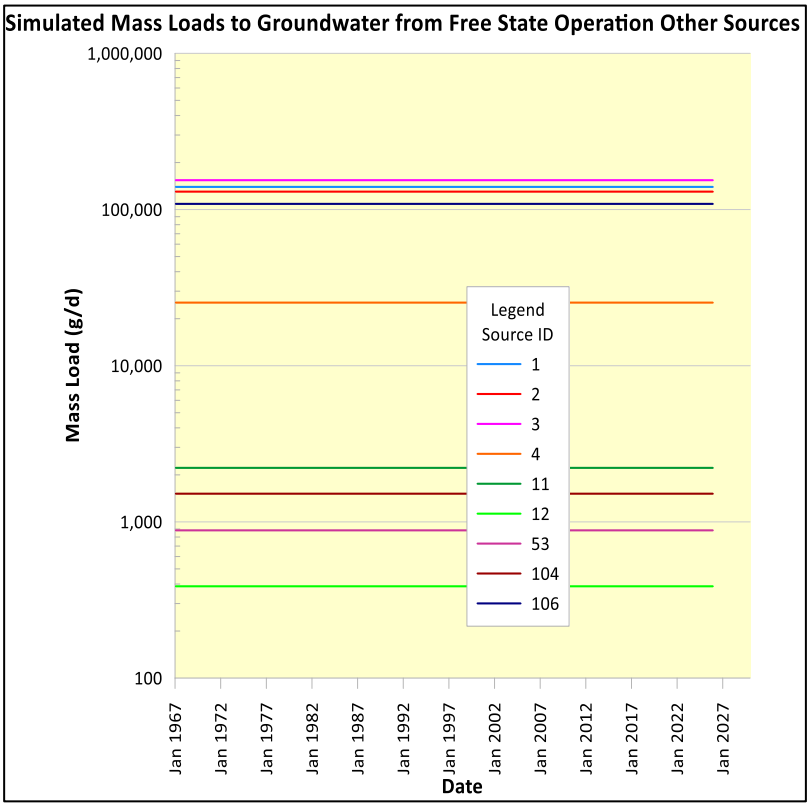


Figure 9-38 – Simulated mass loads to the groundwater pathway from FSS Other sources.

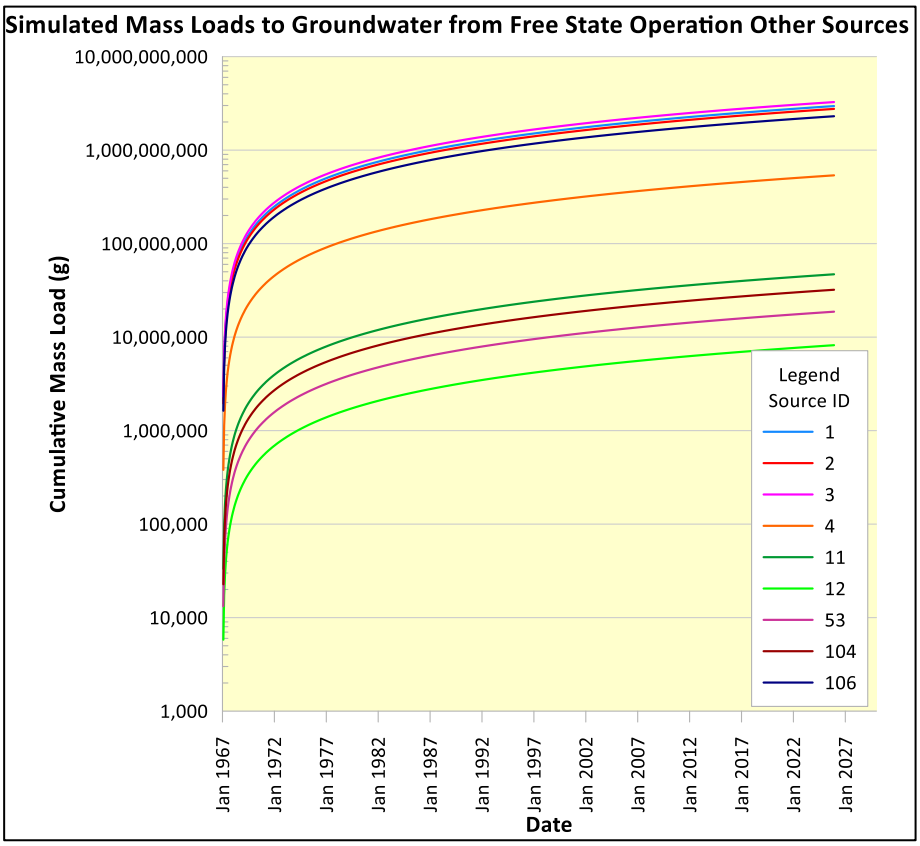


Figure 9-39 - Simulated cumulative mass loads to the groundwater pathway from FSS Other sources.

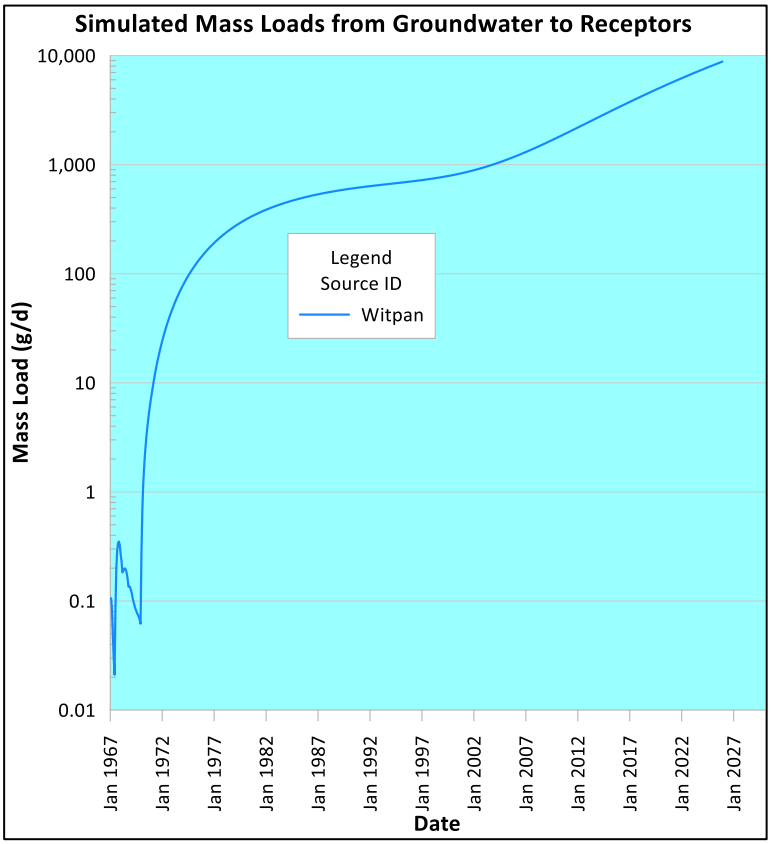


Figure 9-40 – Simulated mass loads from the groundwater pathway to receptors.

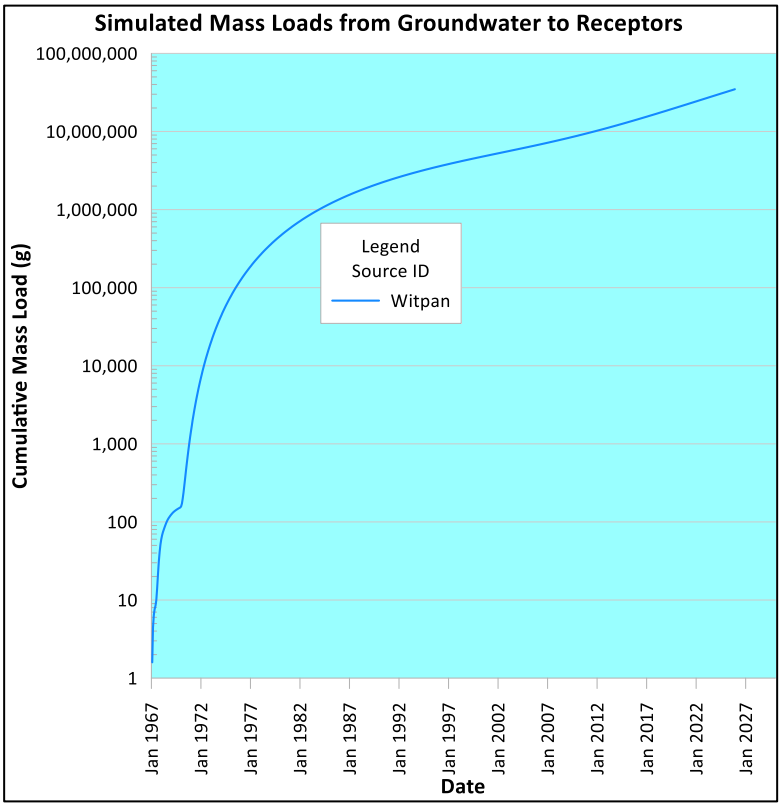


Figure 9-41 – Simulated cumulative mass loads from the groundwater pathway to receptors.

9.7 Operations in and around the Brand A and D Dams; Saaiplaas SP 1,2,3,4,5A,5B and 6 Dams and Dams 21/H3 and 23/H4

9.7.1 Location

The Harmony Free State Brand A and D Dams; Saaiplaas SP 1,2,3,4,5A,5B and 6 Dams and Dams 21/H3 and 23/H4 are situated southeast of the town of Welkom and to the north of the Sand River (Figure 9-42).

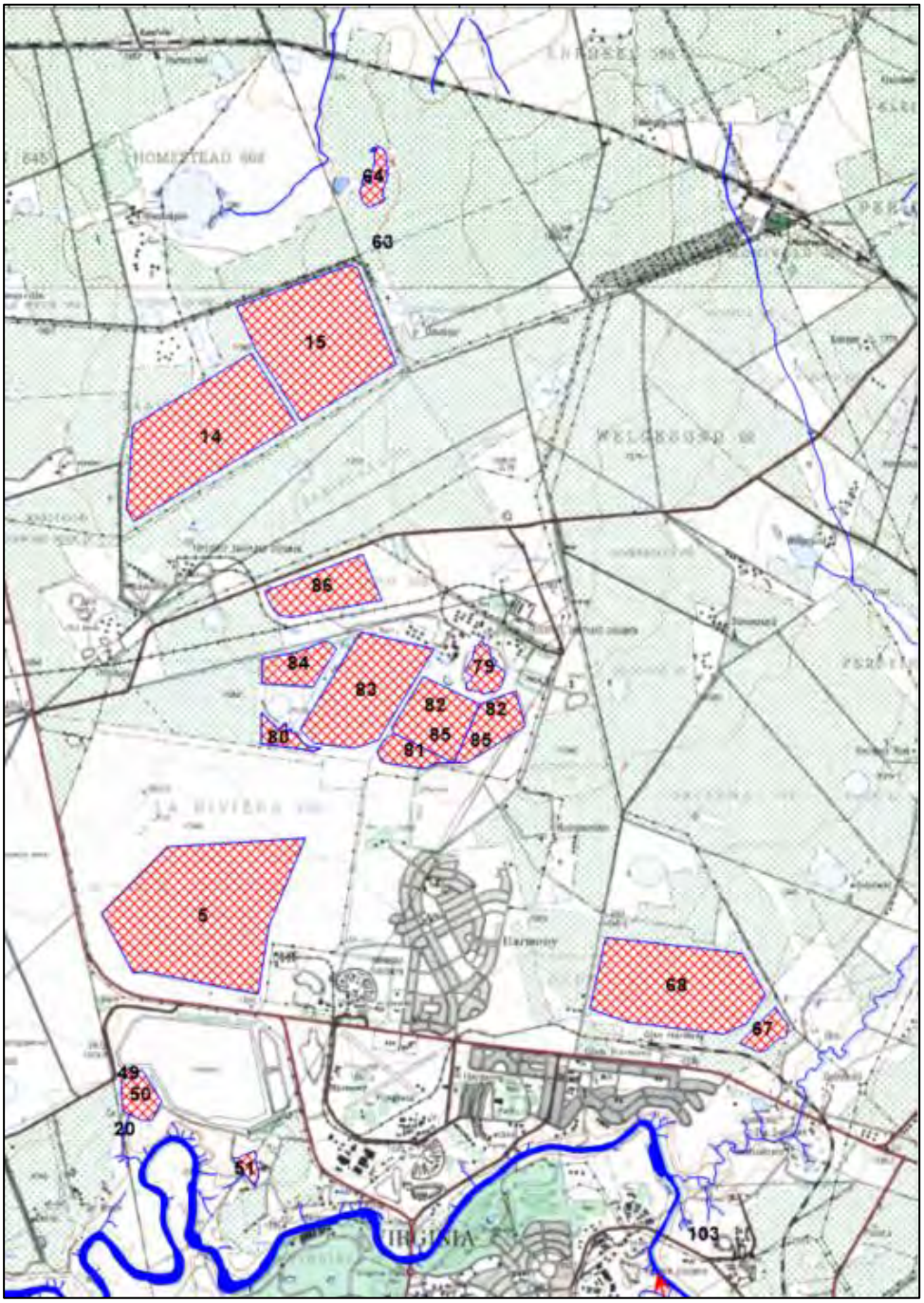


Figure 9-42 – Location of the Harmony Free State Brand A and D Dams; Saaiplaas SP 1,2,3,4,5A,5B and 6 Dams and Dams 21/H3 and 23/H4 and Surrounding sources. Sources are indicated by the red cross-hatched areas.

9.7.2 Sources

The sources depicted on Figure 9-42 are described in Table 9-6. The main sources in terms of size and contamination are the Brand TSF's, Saaiplaas TSF's and Dams 21/H3 and 23/H4.

9.7.3 Groundwater Elevation Contours and Flow Directions

The groundwater elevation contours and groundwater flow directions are depicted in Figure 9-43. The regional groundwater flow follows the regional topography which is from north to south towards the Sand River. The Sand River will form the Receptors in the SPR analysis.

Table 9-6 – Harmony Free State Brand A and D Dams; Saaiplaas SP 1,2,3,4,5A,5B and 6 Dams and Dams 21/H3 and 23/H4 source description.

No on Maps	ID	Source	Purpose/Description	SEEPAGE RATE (m/d)	CONCENTRATION (mg/l)	FEFLOW (mg/l*m/d)
14	S_G3	Brand A Slimes Dam Complex	Tailings storage facility (Reclamation)	0.000142274	1942	0.276296
15	C_G4	Brand D Slimes Dam Complex	Tailings storage facility	0.000142274	1942	0.276296
79	S_G2	Saaiplaas 2 Shaft Waste Rock Dump	Waste rock dump (dormant)	4.74247E-05	96	0.004553
80	S_G9	Saaiplaas No. 3 Return Water Dam	Return water dam	0.000142274	2255	0.320828
81	S_G10	Saaiplaas No. 5 Return Water Dam	Return water dam	0.000142274	1356	0.192924
82	S_G5	Saaiplaas Return Water Dams 1 & 2	Return water dams (dormant)	0.000142274	1526	0.217110
83	S_G4	Saaiplaas Slimes Dam Complex (Slimes dam 1, 2 & 3)	Tailings storage facilities (dormant)	0.000142274	1942	0.276296
84	S_G6	Saaiplaas Slimes Dam Complex 4	Tailings storage facilities	0.000142274	1942	0.276296
85	S_G7	Saaiplaas Slimes Dam Complex 5a & 5b	Tailings storage facilities (dormant)	0.000142274	1942	0.276296
86	S_G8	Saaiplaas Slimes Dam Complex 6	Tailings storage facilities (dormant)	0.000142274	1942	0.276296
5	S_G11	21/H3 Slimes Dam	Tailings storage facility (dormant - reprocessing)	0.000142274	1942	0.276296
67	C_G6	No 23 (H4) Return Water Dam	Return water dam	0.000142274	1526	0.217110
68	C_G5	No. 23 (H4) Slimes Dam Complex	Tailings storage facility	0.000142274	1942	0.276296
49	C_G7	Harmony A-Dam	Return water dam	0.000142274	1000	0.142274
50	C_G8	Harmony B-Dam	Return water dam	0.000142274	1526	0.217110
51	C_G9	Harmony C-Dam	Return water dam	0.000142274	1526	0.217110
20	S_G1	D-Dam (Virginia)	Storage of Excess water for reuse	0.000142274	1606	0.228492
103	C_G2	Virginia 2 Shaft Waste Rock Dump	Waste rock dump (dormant)	4.74247E-05	96	0.004553
63	H_G4	Masimong 4 Hot Water Dam	Excess water for reuse	0.000142274	1000	0.142274
64	H_G17	Masimong 4 Waste Rock Dump	Waste rock dump (dormant)	4.74247E-05	96	0.004553

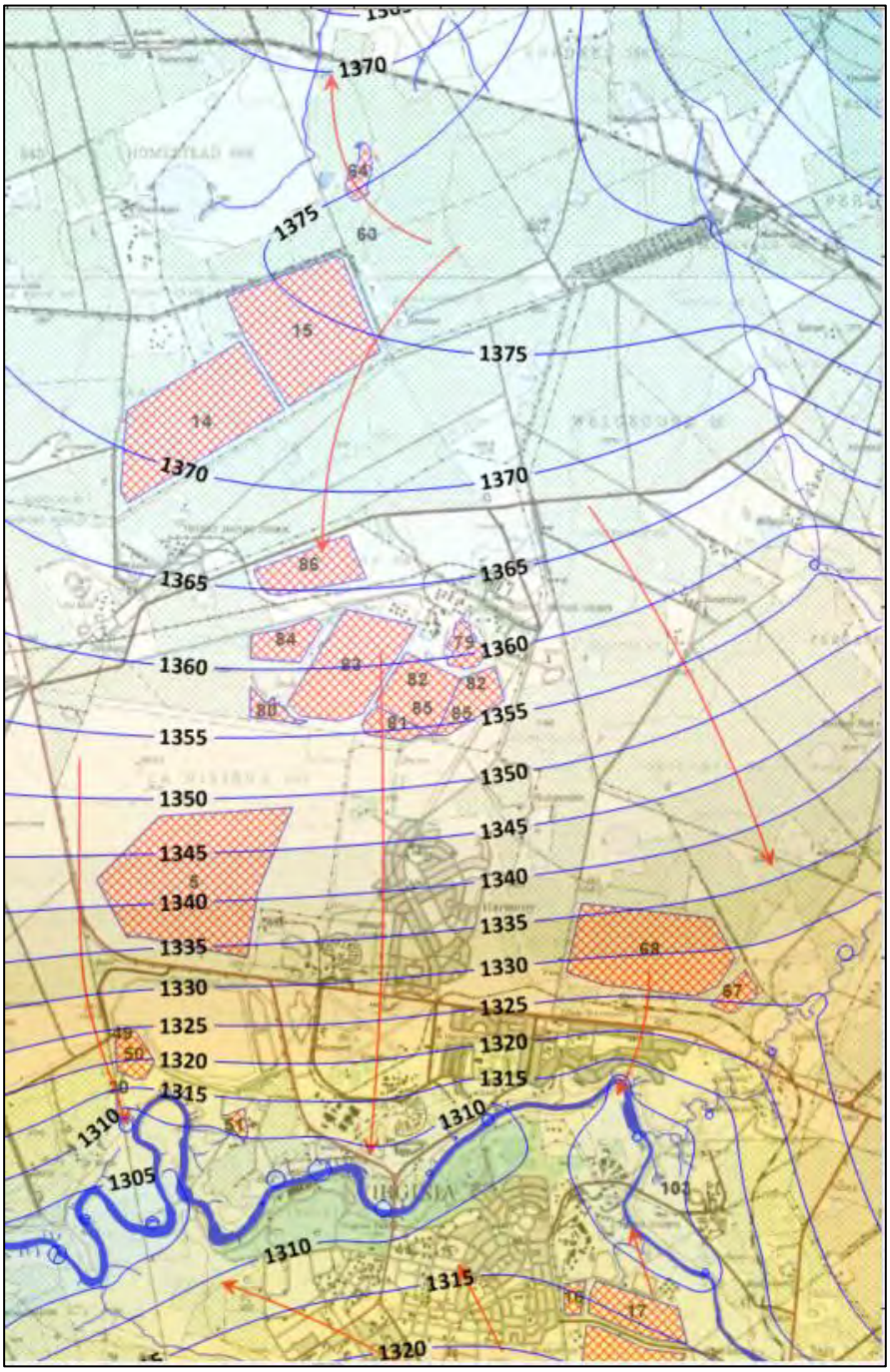


Figure 9-43 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows.

9.7.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes

The simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes are depicted in Figure 9-44. From this figure it is evident that the sulphate migrates to the south towards the Sand River.

In general, the correspondence between the simulated sulphate concentrations and the observed sulphate concentrations in the boreholes is good from a qualitative perspective. The map in general indicates that the simulated plumes overlap with areas of poorer observed water qualities. It is also

evident from the map that in most cases where observed qualities seem unaffected that the model prediction agrees.

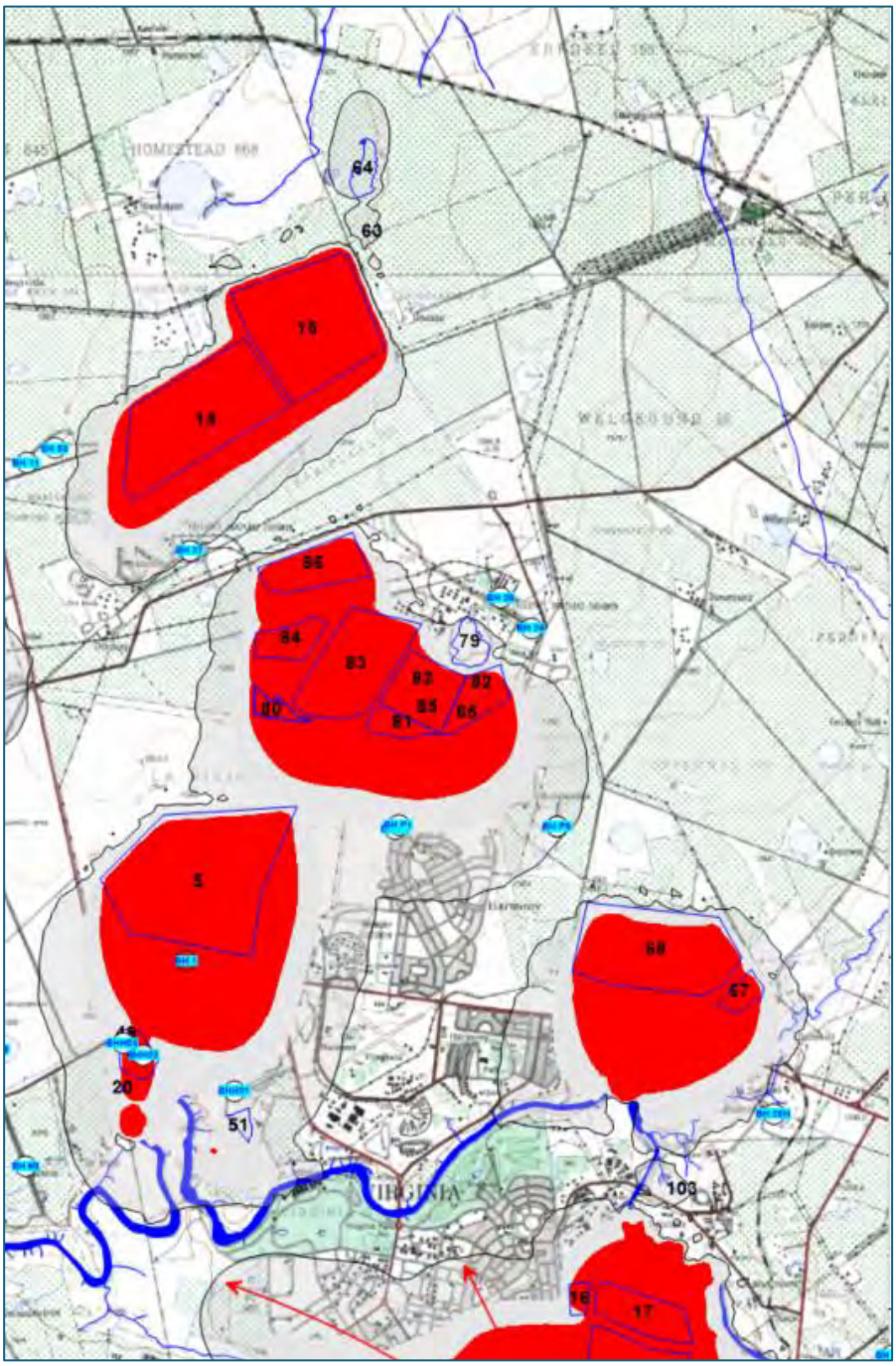


Figure 9-44 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers).

9.7.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR)

The mass loads and cumulative mass loads from the Brand sources to the groundwater pathway are depicted in Figure 9-45 and Figure 9-46 respectively.

The mass loads and cumulative mass loads from the Saaiplaas sources to the groundwater pathway are depicted in Figure 9-47 and Figure 9-48 respectively.

The mass loads and cumulative mass loads from the 21/H3 & 23/H4 sources to the groundwater pathway are depicted in Figure 9-49 and Figure 9-50 respectively.

The mass load from the groundwater pathway to the receptor (Sand River) is depicted in Figure 9-51 and the cumulative mass loads from the groundwater pathway to the receptors depicted in Figure 9-52.

From the graphs presented the following is evident:

- Sources 14 (Brand A Slimes Dam) and 15 (Brand D Slimes Dam) contribute about 964 kg/d to the groundwater pathway.
- The Saaiplaas sources (79-86) contribute about 803 kg/d to the groundwater pathway.
- The No. 21/H3 (5) and No. 23/H4 (68) TSF's contribute 1072 kg/d to the groundwater pathway.
- The largest impact from the groundwater pathway to a surface receptor is to the Sand River where about 223 kg/d is reporting at the end of 2025. This includes mass loads from sources to the south of the Sand River.

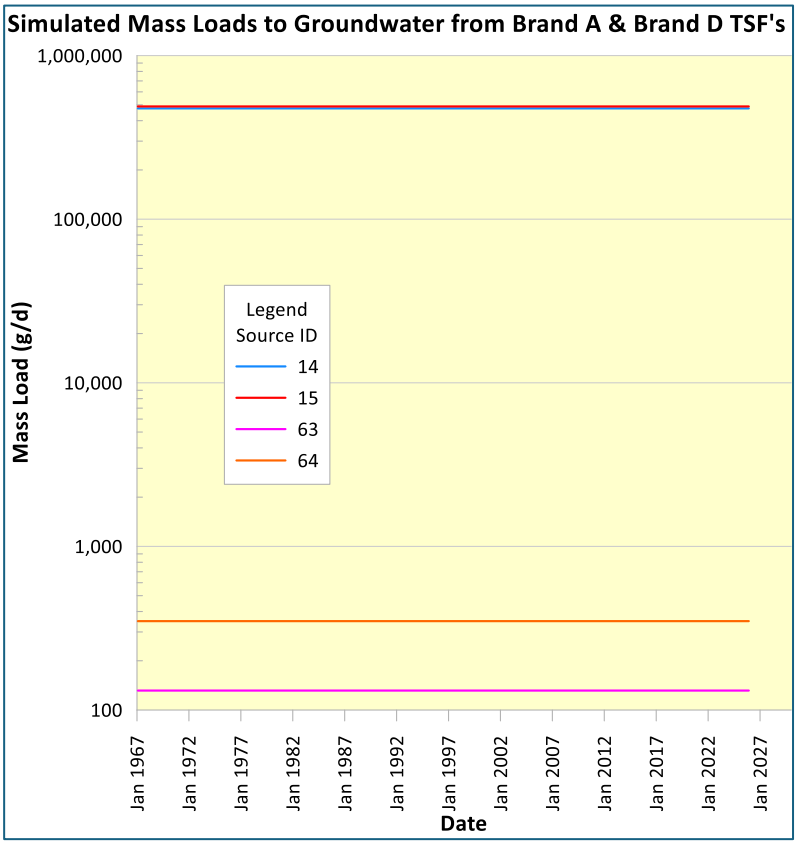


Figure 9-45 – Simulated mass loads to the groundwater pathway from Brand sources.

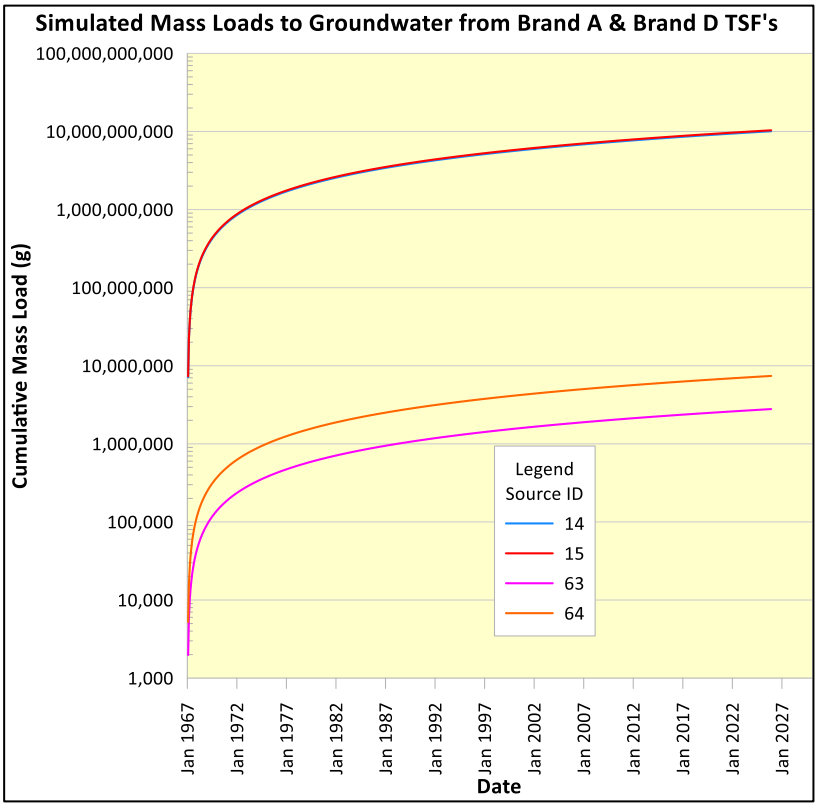


Figure 9-46 - Simulated cumulative mass loads to the groundwater pathway from Brand sources.

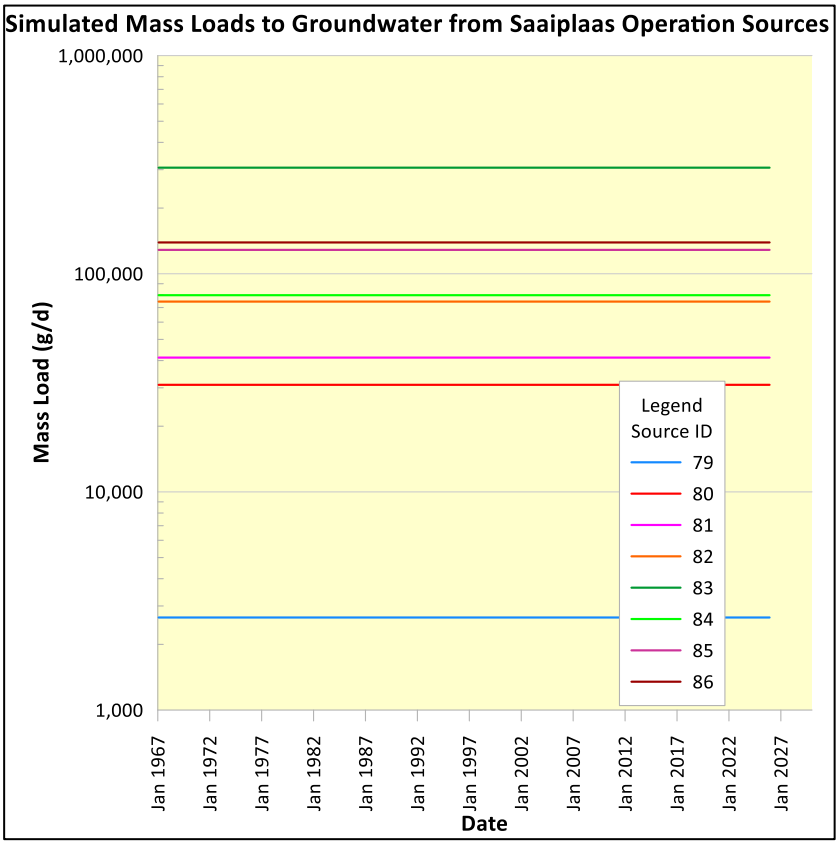


Figure 9-47 – Simulated mass loads to the groundwater pathway from Saaiplaas sources.

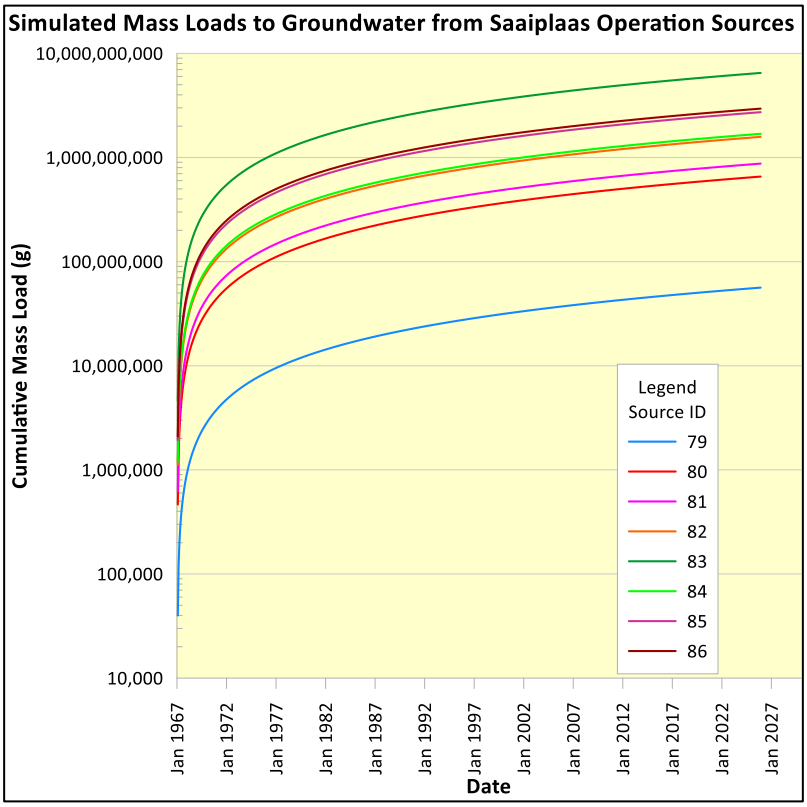


Figure 9-48 - Simulated cumulative mass loads to the groundwater pathway from Saaiplaas sources.

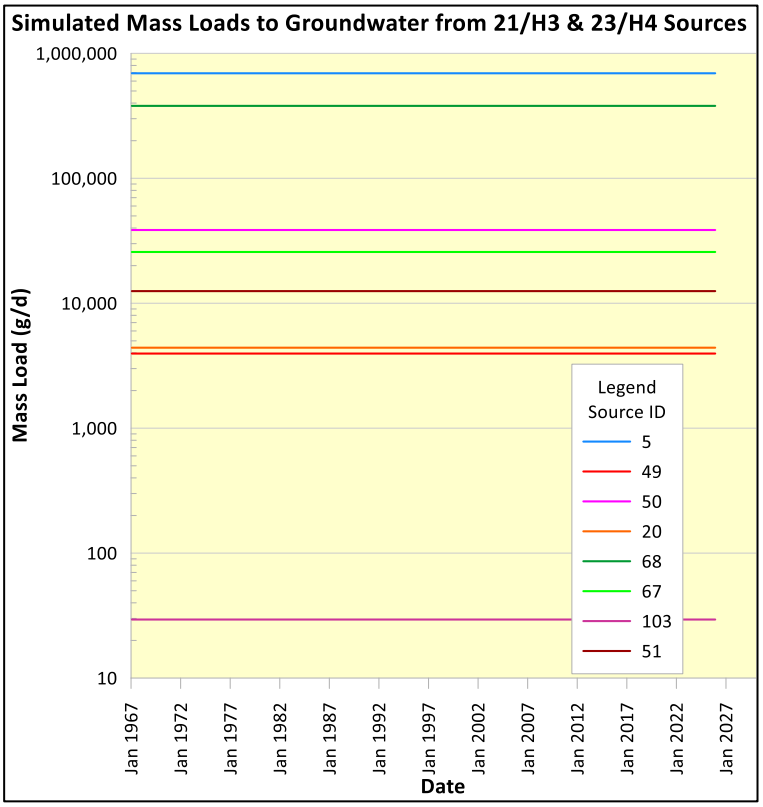


Figure 9-49 – Simulated mass loads to the groundwater pathway from 21/H3 & 23/H4 sources.

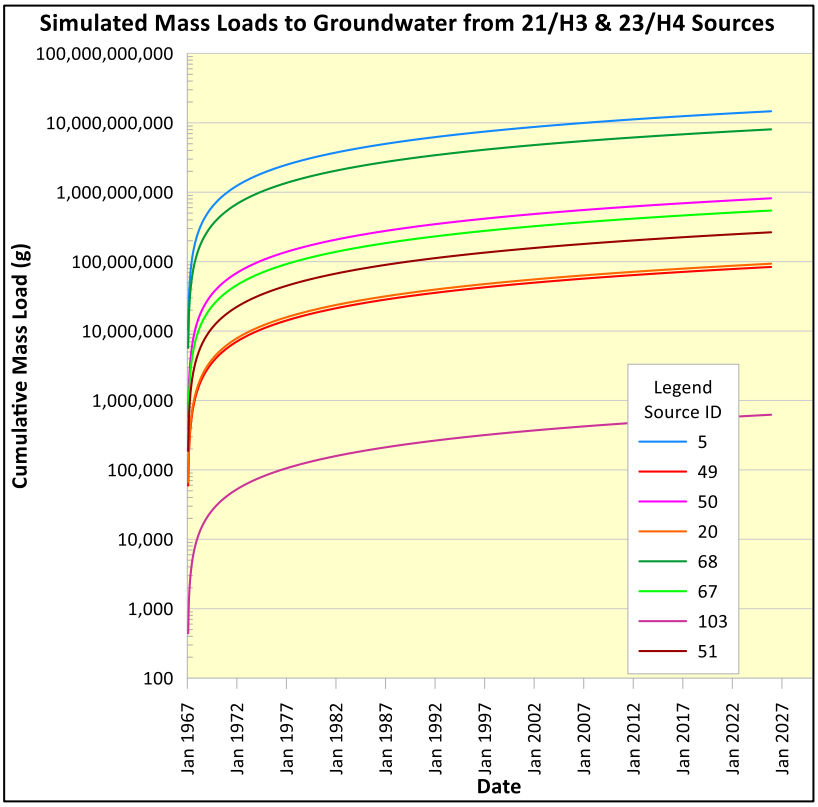


Figure 9-50 - Simulated cumulative mass loads to the groundwater pathway from 21/H3 & 23/H4 sources.

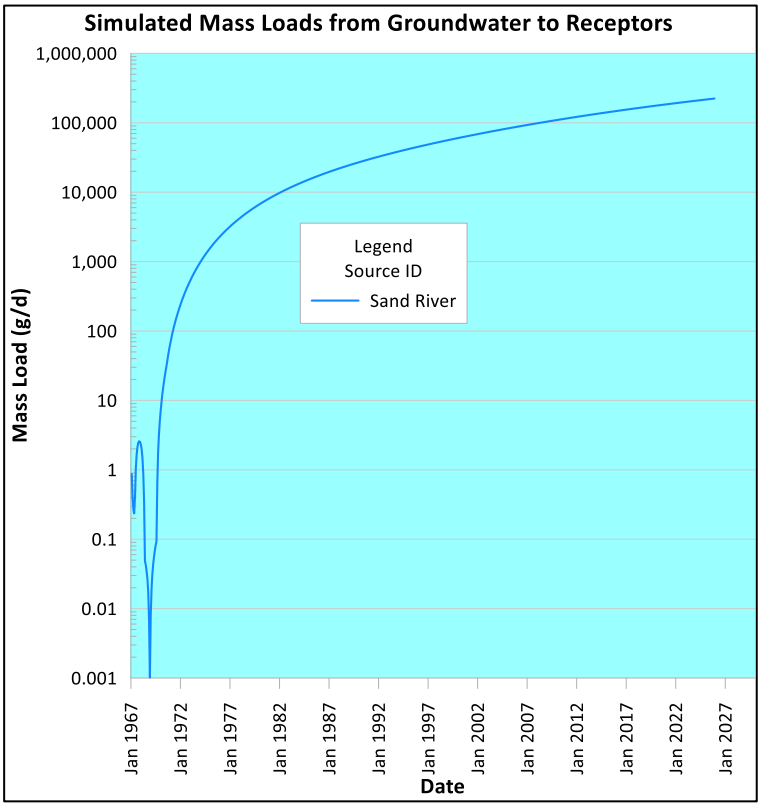


Figure 9-51 – Simulated mass loads from the groundwater pathway to receptors.

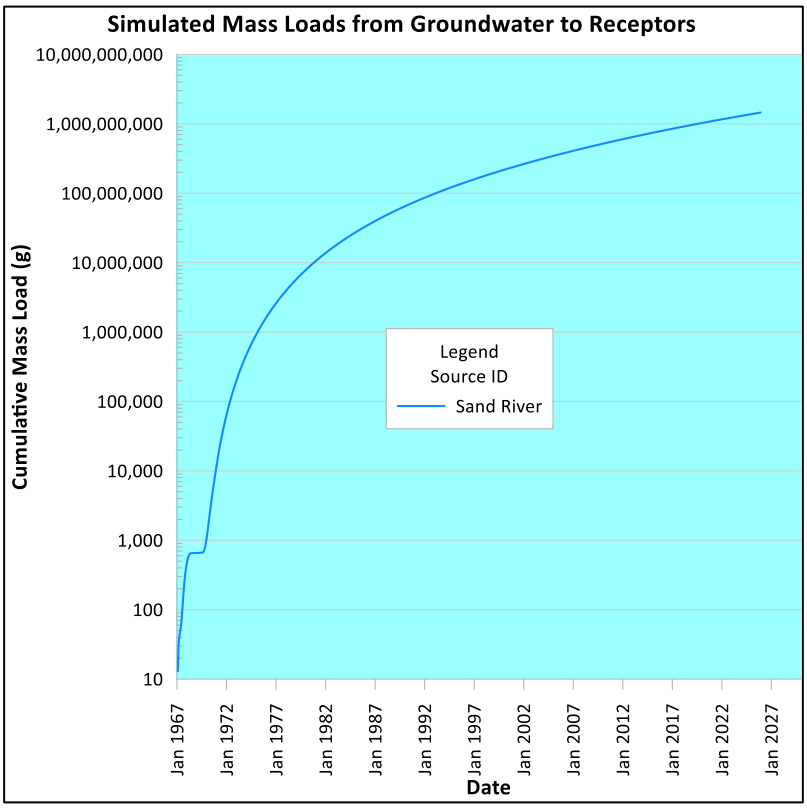


Figure 9-52 – Simulated cumulative mass loads from the groundwater pathway to receptors.

9.8 Harmony Virginia Free State Dams

9.8.1 Location

The Harmony Virginia Free State Dams; No. 30A, 30B, 31, 32, 33A, 33B, 34A and 34B as well as Calcine Dams No. 25 and No.27 are situated south of the town of Virginia and to the south of the Sand River (Figure 9-53).

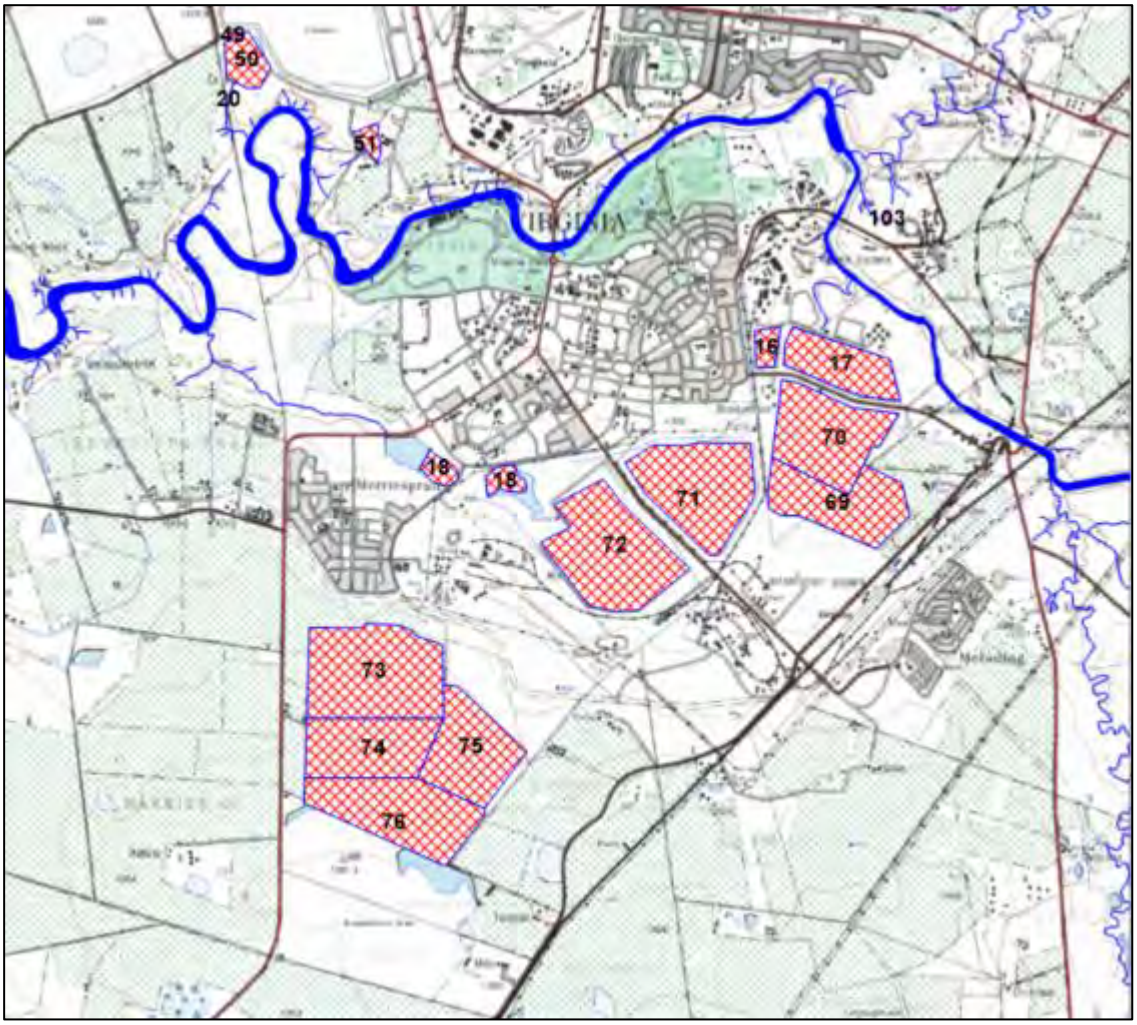


Figure 9-53 – Location of the Harmony Virginia Free State Dams; No. 30A, 30B, 31, 32, 33A, 33B, 34A and 34B as well as Calcine Dams No. 25 and No.27. Sources are indicated by the red cross-hatched areas.

9.8.2 Sources

The sources depicted on Figure 9-53 are described in Table 9-7.

9.8.3 Groundwater Elevation Contours and Flow Directions

The groundwater elevation contours and groundwater flow directions are depicted in Figure 9-54. The regional groundwater flow follows the regional topography which is from south to north towards the Sand River. The Sand River will form the Receptor in the SPR analysis.

Table 9-7 – Harmony Virginia Free State Dams source description.

No on Maps	ID	Source	Purpose/Description	SEEPAGE RATE (m/d)	CONCENTRATION (mg/l)	FEFLOW (mg/l*m/d)
16	C_G11	Calcine Slimes Dam 25	Tailings storage facility (dormant)	0.000142274	1942	0.276296
17	C_G12	Calcine Slimes Dam 27	Tailings storage facility (dormant - reclaimed)	0.000142274	1942	0.276296
18	C_G1	Convent Dam (upper and lower)	Storage of process water	0.000142274	1000	0.142274
69	C_G13	No. 30A Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
70	C_G14	No. 30B Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
71	C_G15	No. 31 Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
72	C_G16	No. 32 Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
73	C_G17	No. 33A Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
74	C_G18	No. 33B Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
75	C_G19	No. 34 A Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296
76	C_G20	No. 34 B Slimes Dam	Tailings storage facility (dormant)	0.000142274	1942	0.276296

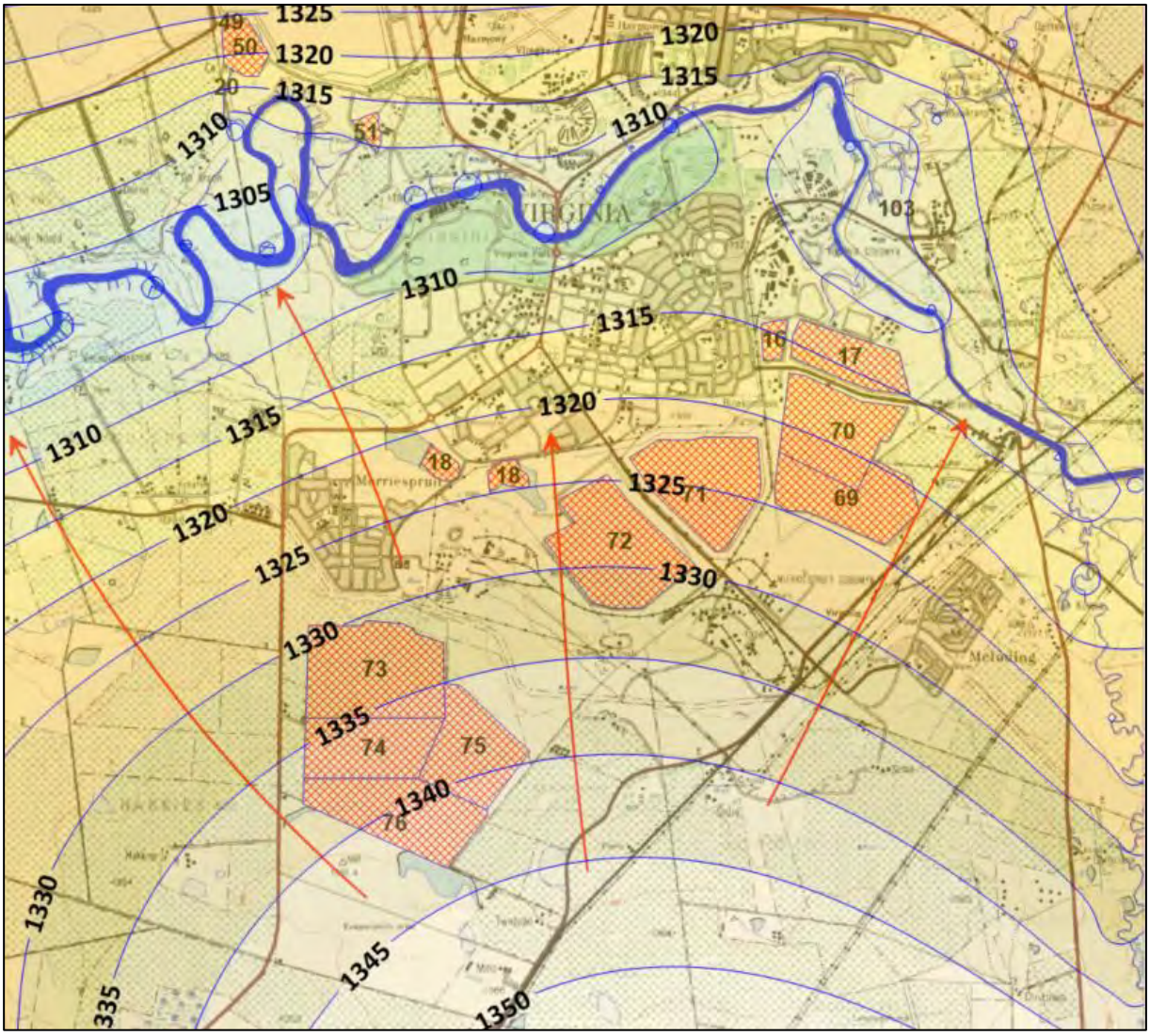


Figure 9-54 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows.

9.8.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes

The simulated sulphate plume concentrations and observed sulphate concentrations at the

monitoring boreholes are depicted in Figure 9-55. From this figure it is evident that the sulphate migrates to the north towards the Sand River.

The spatial distribution of observation boreholes is sparse in the area and a qualitative analysis between simulated and observed concentrations is not possible.

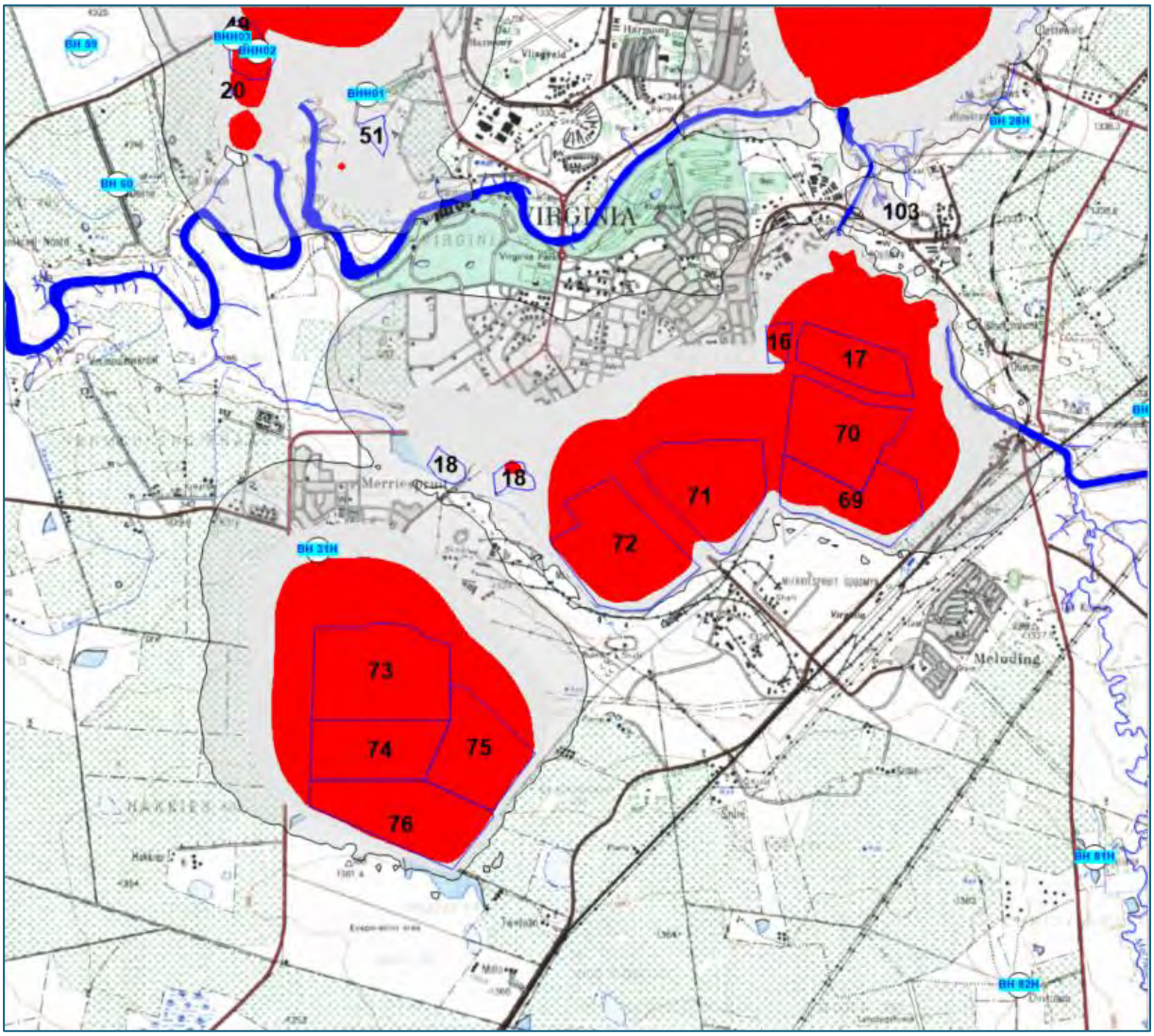


Figure 9-55 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers).

9.8.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR)

The mass loads and cumulative mass loads from the Calcine sources and Convent Dams to the groundwater pathway are depicted in Figure 9-56 and Figure 9-57 respectively.

The mass loads and cumulative mass loads from the Dams No. 30A, 30B, 31 and 32 to the groundwater pathway are depicted in Figure 9-58 and Figure 9-59 respectively.

The mass loads and cumulative mass loads from the Dams No. 33A, 33B, 34A and 34 B to the groundwater pathway are depicted in Figure 9-60 and Figure 9-61 respectively.

The mass load from the groundwater pathway to the receptor (Sand River) is depicted in Figure 9-51 and the cumulative mass loads from the groundwater pathway to the receptors depicted in Figure 9-52.

From the graphs presented the following is evident:

- Sources 16 & 17 (Calcine Slimes Dams 25&27) and 18 (Convent Dam Upper & Lower) contribute about 135 kg/d to the groundwater pathway.
- The sources Dams No. 30A, 30B, 31 and 32 (69-72) contribute about 820 kg/d to the groundwater pathway.
- The sources Dams No. 33A, 33B, 34A and 34 B (73-76) contribute 973 kg/d to the groundwater pathway.
- The largest impact from the groundwater pathway to a surface receptor is to the Sand River where about 223 kg/d is reporting at the end of 2025. This includes mass loads from sources to the south of the Sand River as well as to the north of the Sand River.

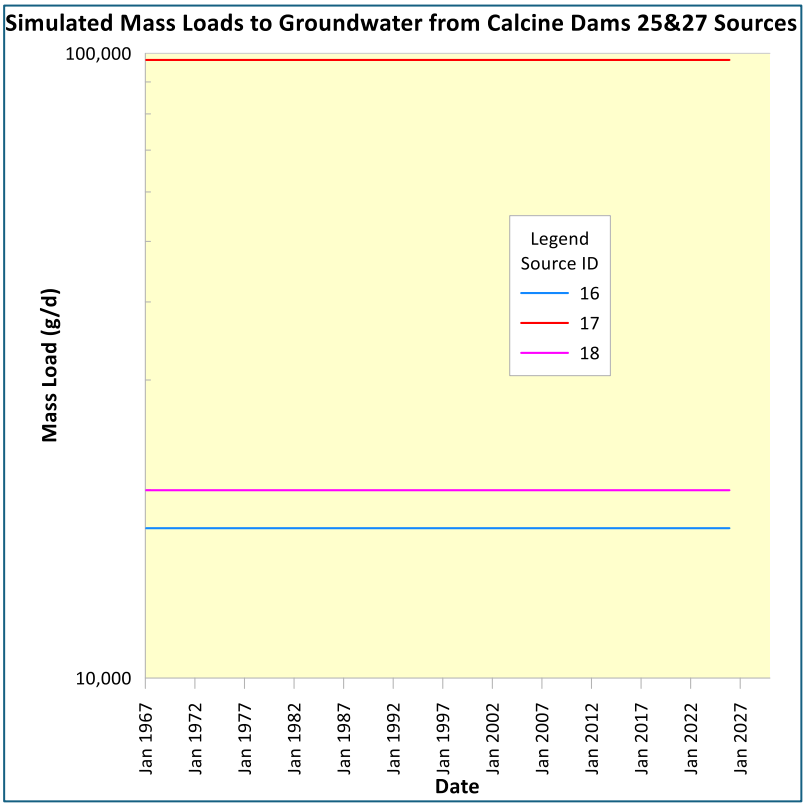


Figure 9-56 – Simulated mass loads to the groundwater pathway from Calcine sources and Convent Dams.

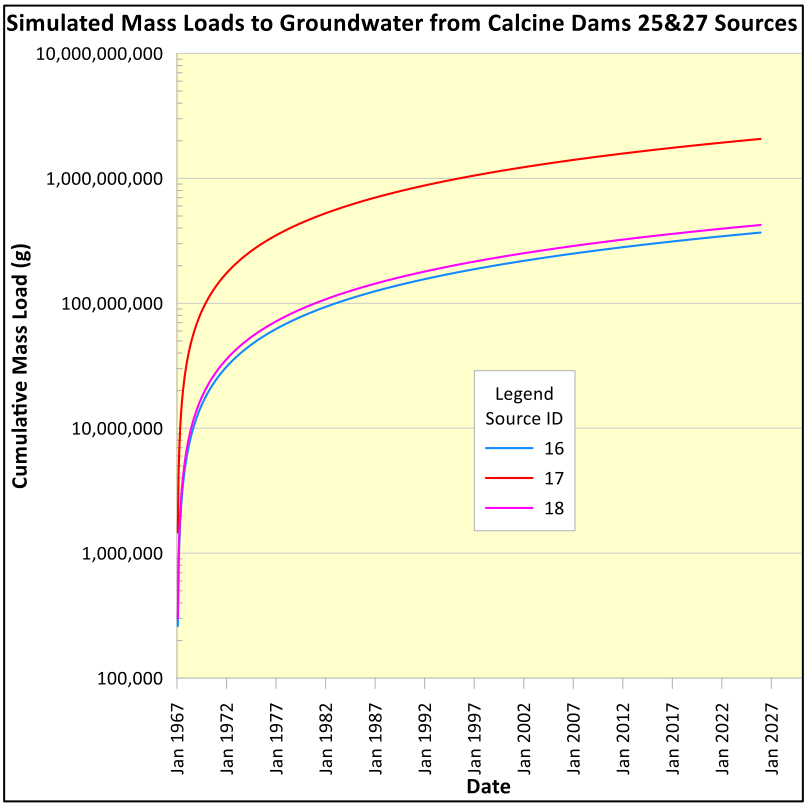


Figure 9-57 - Simulated cumulative mass loads to the groundwater pathway from Calcine sources and Convent Dams.

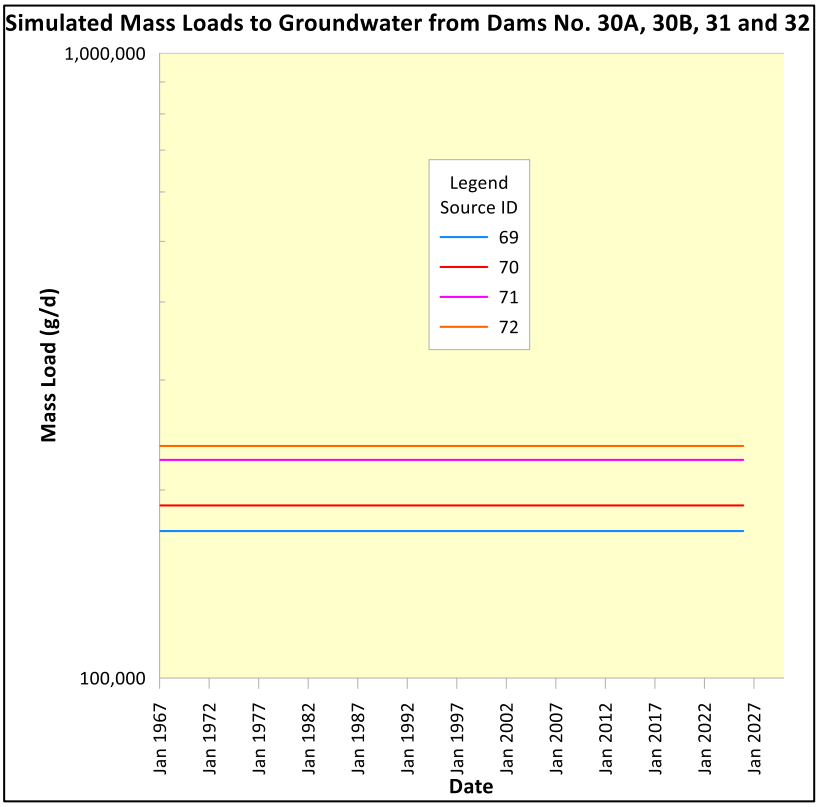


Figure 9-58 – Simulated mass loads to the groundwater pathway from Dams No. 30A, 30B, 31 and 32.

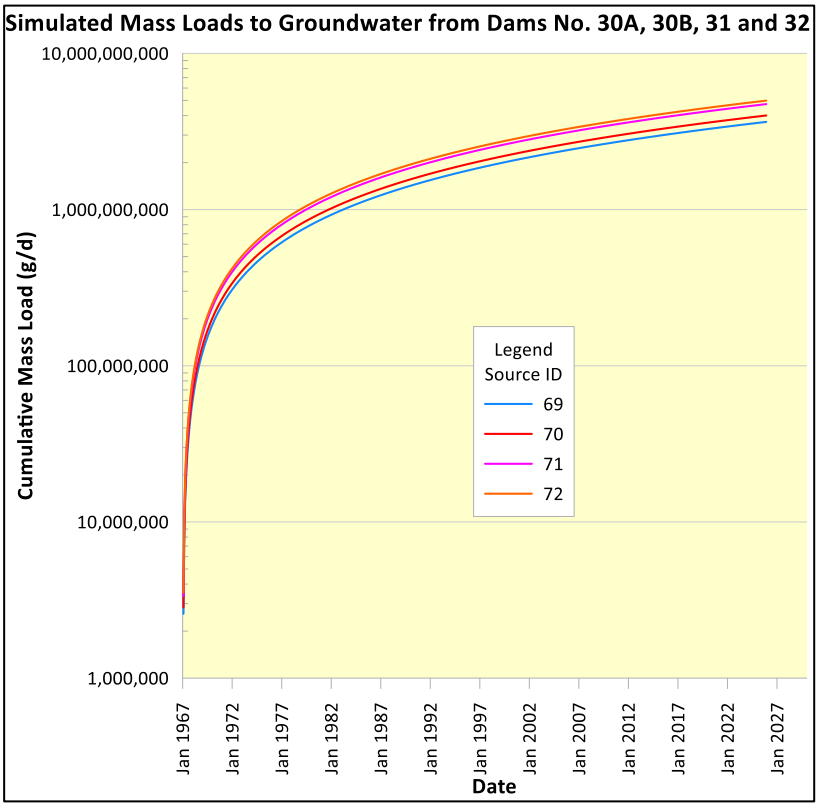


Figure 9-59 - Simulated cumulative mass loads to the groundwater pathway from Dams No. 30A, 30B, 31 and 32.

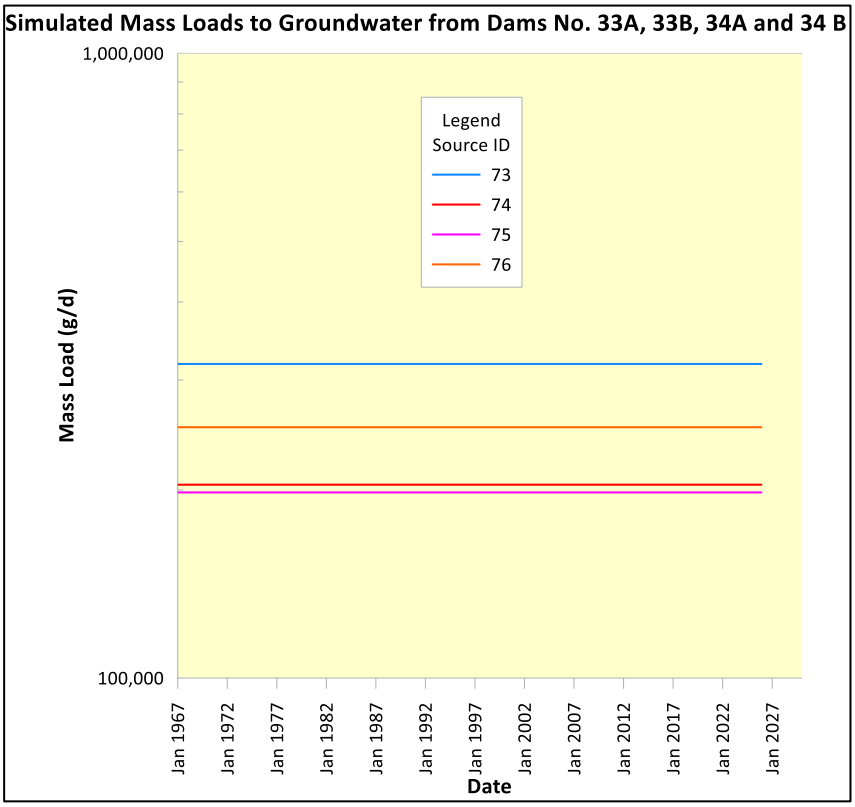


Figure 9-60 – Simulated mass loads to the groundwater pathway from Dams No. 33A, 33B, 34A and 34 B.

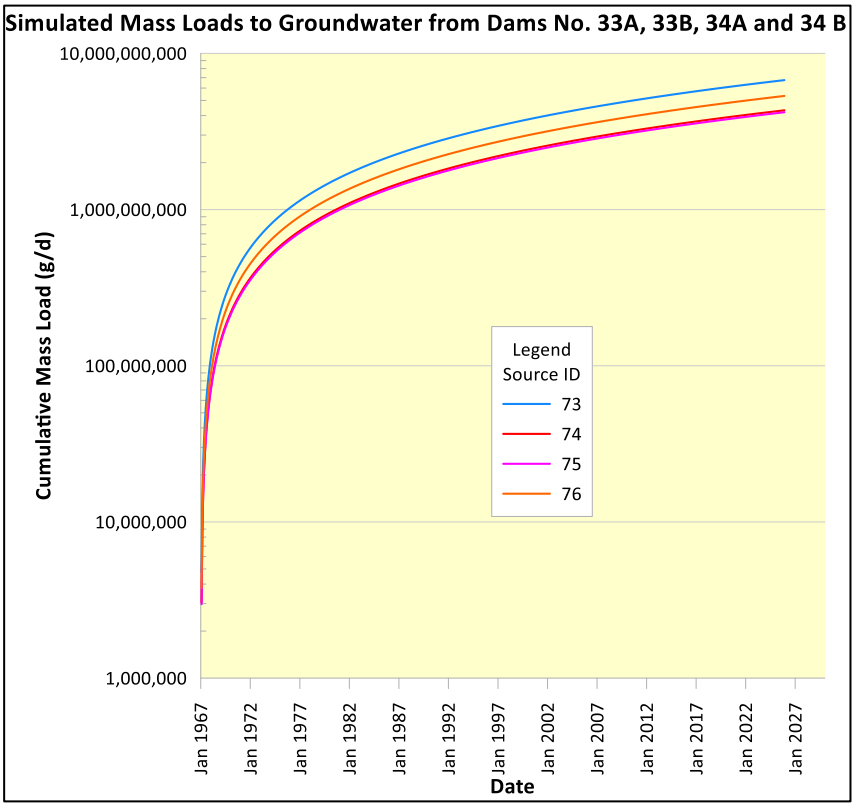


Figure 9-61 - Simulated cumulative mass loads to the groundwater pathway from Dams No. 33A, 33B, 34A and 34 B.

9.9 Operations in the Joel Mine Area

9.9.1 Location

The Joel Mine Operations are situated about 20 km southwest of the town of Virginia and on a watershed between the Theron Spruit to the west and the Doring River to the east as depicted on Figure 9-62.

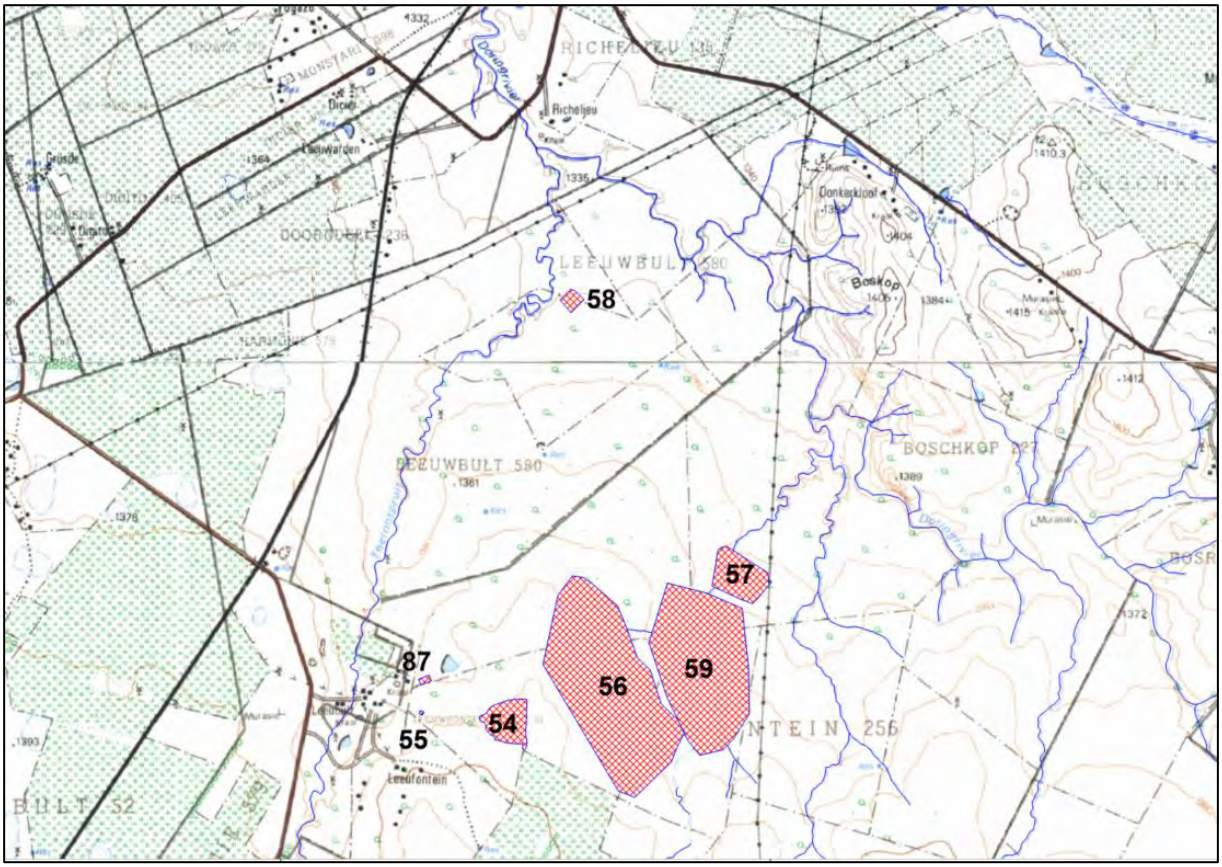


Figure 9-62 – Location of the Joel Mine Operation. Sources are indicated by the red cross-hatched areas.

9.9.2 Sources

The sources depicted on Figure 9-62 are described in Table 9-8. The main sources in terms of size and contamination are the Joel Evaporation Dams and the Joel Slime Dam Complex.

Table 9-8 – Joel Mine Operations source description.

No on Maps	ID	Source	Purpose/Description	SEEPAGE RATE (m/d)	CONCENTRATION (mg/l)	FEFLOW (mg/l*m/d)
54	J_G4	Joel 3 South (Taung South) Shaft Waste Rock Dump	Waste rock dump (dormant)	4.74247E-05	96	0.004553
55	J_G2	Joel 3 South Shaft TK1 Water Tank	Contains water abstracted from underground	1.00E-06	186	0.000186
56	J_G1	Joel Evaporation Dams	Excess water from the shafts and return water dam (emergency use only)	0.000142274	978	0.139144
57	J_G6	Joel Return Water Dam	Return Water Dam	0.000142274	1000	0.142274
58	J_G3	Joel Sewage Plant	Sewage treatment plant	1.00E-06	46	0.000046
59	J_G5	Joel Slime Dam Complex	Tailings storage facility (dormant)	0.000142274	1942	0.276296
87	J_G7	Settler Dams	Store slurry from underground	0.000142274	1000	0.142274

9.9.3 Groundwater Elevation Contours and Flow Directions

The groundwater elevation contours and groundwater flow directions are depicted in Figure 9-63. The regional groundwater flow follows the regional topography which is from southeast and southwest to the north following the Theron Spruit and the Doring River. From a groundwater flow point of view, these two surface drainages will form Receptors in the SPR analysis.

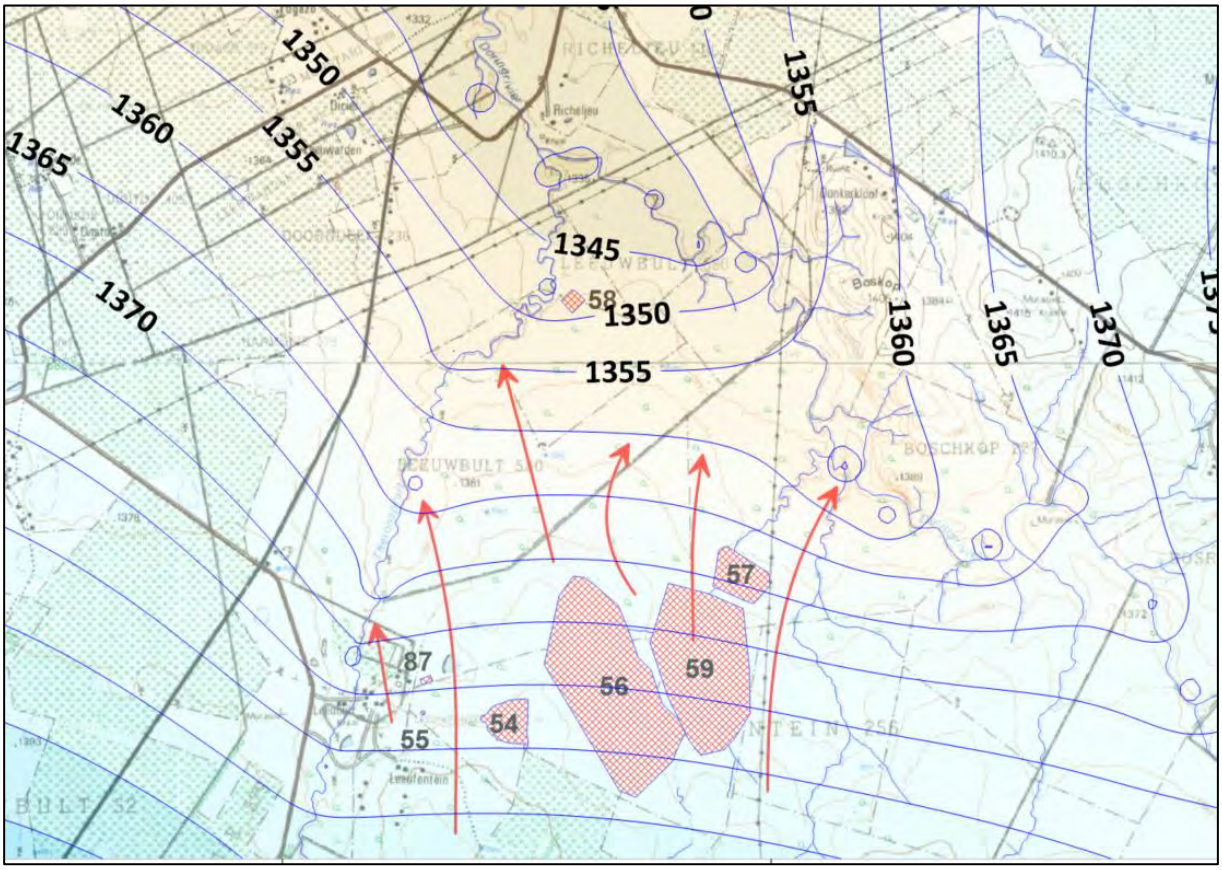


Figure 9-63 – Groundwater Elevation Contours (mamsl) indicated as blue lines and Groundwater Flow Directions as red arrows.

9.9.4 Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes

The simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes are depicted in Figure 9-64. From this figure it is evident that the sulphate migrates to the northwest towards Theron Spruit in the west and to the north and northeast towards the Doring River from the Joel Mine Complex.

In general, the correspondence between the simulated sulphate concentrations and the observed sulphate concentrations in the boreholes is good from a qualitative perspective. The map in general indicates that the simulated plumes overlap with areas of poorer observed water qualities. It is also evident from the map that in most cases where observed qualities seem unaffected that the model prediction agrees.

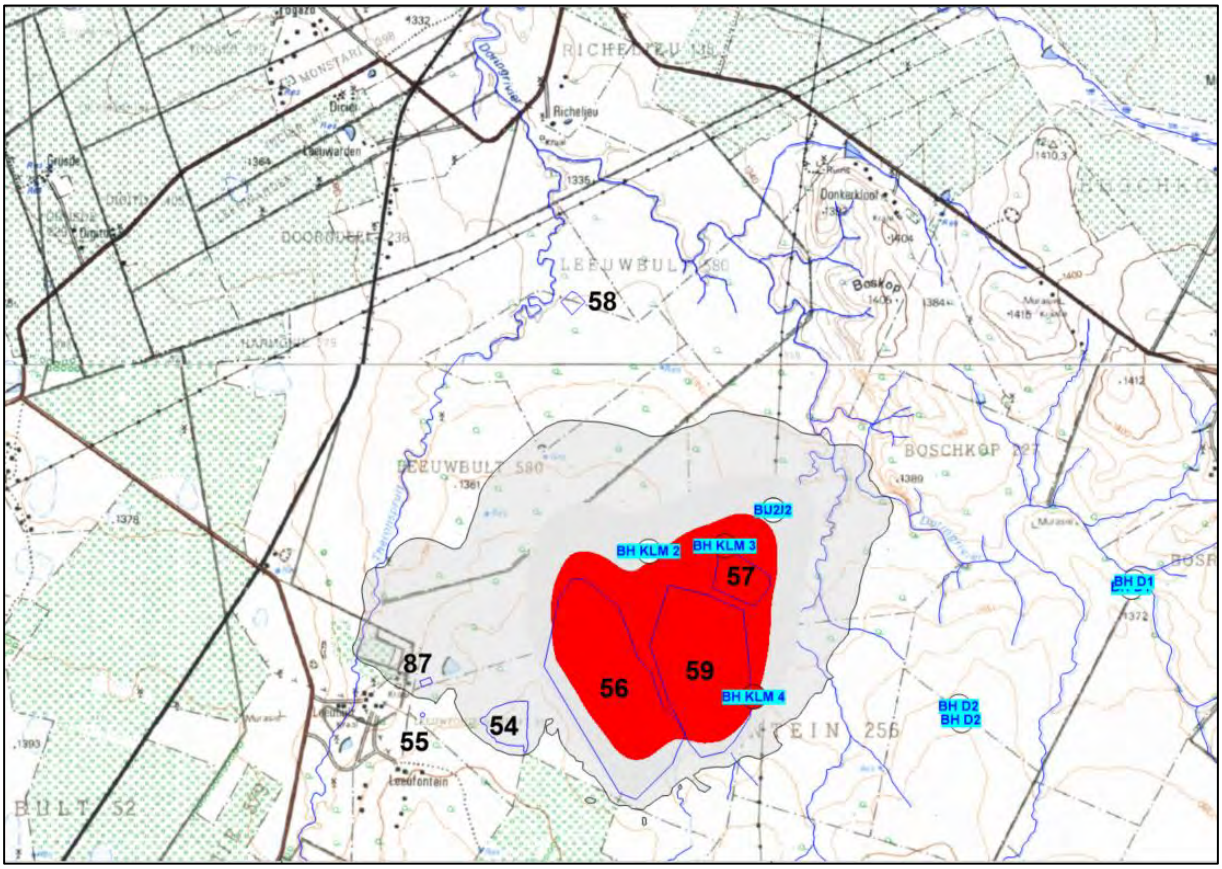


Figure 9-64 - Simulated sulphate plume concentrations and observed sulphate concentrations at the monitoring boreholes (indicated by the blue numbers).

9.9.5 Simulated mass loads and cumulative mass loads from sources to groundwater pathway to receptors (SPR)

The mass loads from the sources to the groundwater pathway are depicted in Figure 9-65 and the cumulative mass loads from the sources to the groundwater pathway depicted in Figure 9-66.

The mass loads from the groundwater pathway to the receptors are depicted in Figure 9-67 and the cumulative mass loads from the groundwater pathway to the receptors depicted in Figure 9-68.

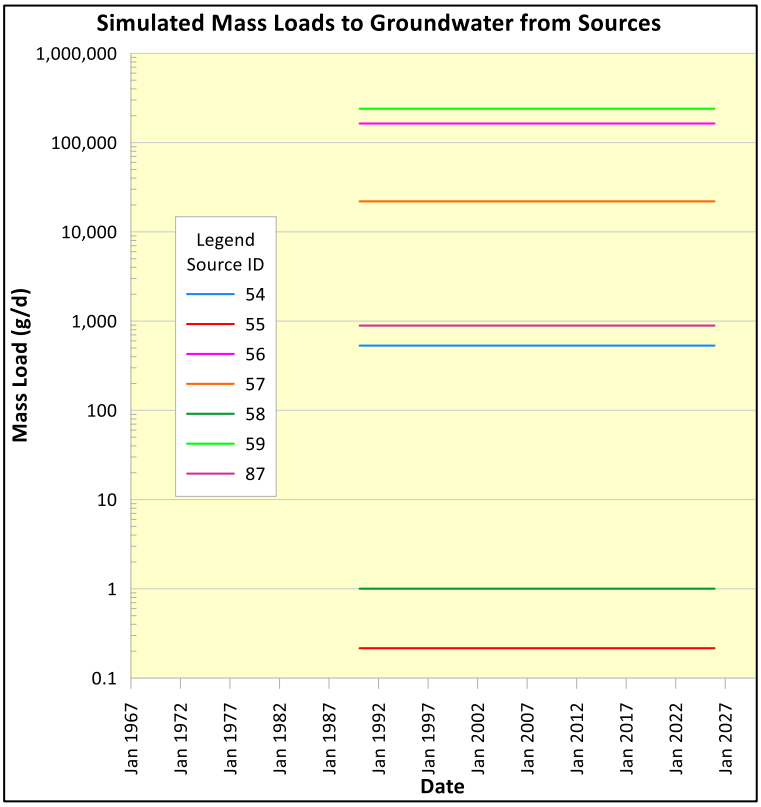


Figure 9-65 – Simulated mass loads to the groundwater pathway from sources.

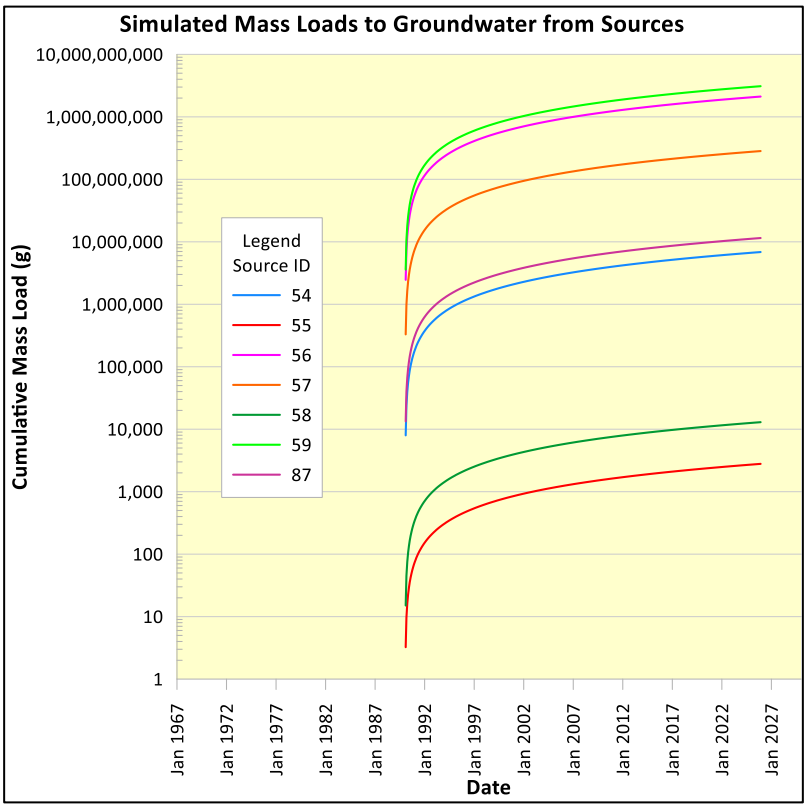


Figure 9-66 - Simulated cumulative mass loads to the groundwater pathway from sources.

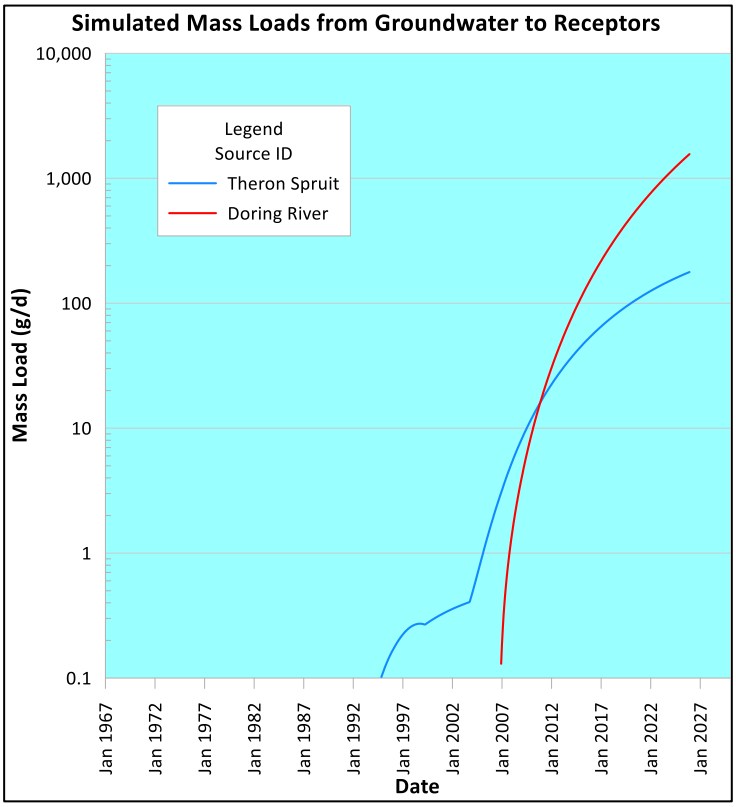


Figure 9-67 – Simulated mass loads from the groundwater pathway to receptors.

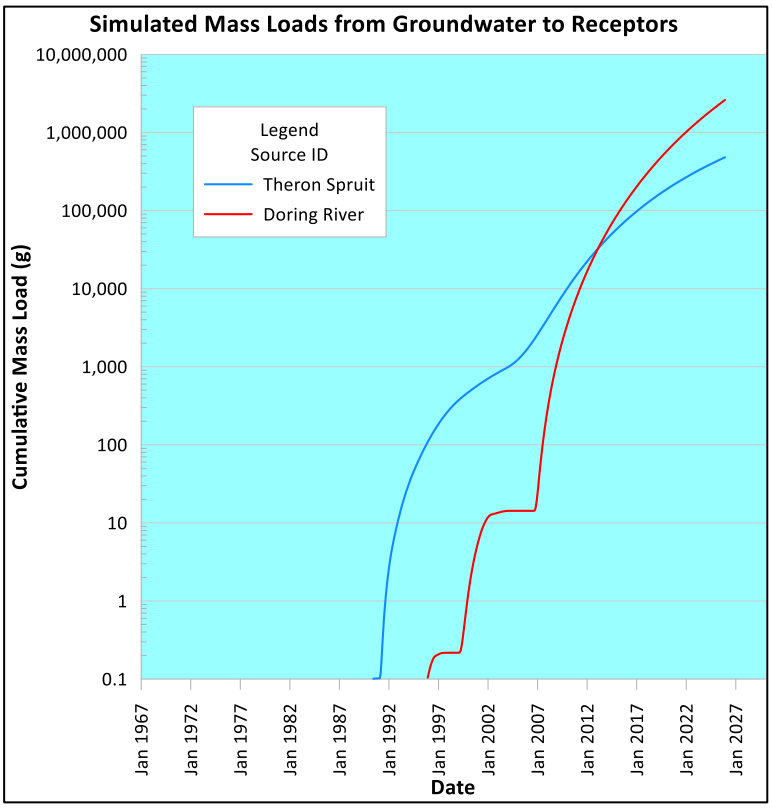


Figure 9-68 – Simulated cumulative mass loads from the groundwater pathway to receptors.

From the graphs presented the following is evident:

- Sources 56 (Joel Evaporation Dams) and 59 (Joel Slime Dam Complex) contribute by far the most mass from sources to the groundwater pathway, about 404 kg/d.
- In comparison, the remainder of the sources contributes in total only about 23 kg/d to the groundwater pathway.
- This is reflected by the simulated sulphate plume shown in Figure 9-64.
- The largest impact (although very small) from the groundwater pathway to a surface receptor is to the Doring River where about 1.50 kg/d is reporting at the end of 2025.
- The impact on the Theron Spruit is less than 0.2 kg/d.

10 Conclusions

With reference to the objectives of this project it is concluded that:

- A preliminary groundwater flow and mass transport model to simulate groundwater flow and mass transport through the aquifers within which the Harmony Welkom Operations function was successfully constructed and calibrated for groundwater flow conditions. The model area is sufficiently large to include all of the Operation's TSF's, WRD's and RWD's. The model domain of the 2025 model update was significantly expanded over the 2017 model domain to more accurately reflect the flow regime.
- This groundwater flow model was further expanded into a mass transport model to simulate the migration of contaminants through the subsurface. The mass transport model was not calibrated quantitatively due to the lack of accurate source terms for the TSF's, WRD's and RWD's. However, assumptions were made on the best information available for source seepage rate, source concentration and source commencement date for each of the 106 sources. This is a huge improvement on the assumptions used for the 2017 model update where a constant concentration boundary condition of 100mg/l of sulphate was assigned across all of the various TSF's. Also, the 2025 model includes sources like WRD's and RWD's that was not considered in the 2017 update. This allowed for the simulation of determination of contaminant migration and velocity of contaminant migration. A qualitative assessment of the simulated and observed situations indicated a reasonable correspondence.
- The model can also be used to address aspects related to the risks that both radioactive material and AMD pose to groundwater if so required.
- The model established can further be used with minimum customization to address groundwater management aspects that could form part of the process of developing an Integrated Water and Waste Management Plan (IWWMP) of the activities of Harmony Welkom Operations across the region.
- The model constructed is based on the very flexible Wasy Feflow modelling package. It can be used in future to ascertain the groundwater impacts of future development scenarios or general groundwater management across the region.

11 Recommendations

The following data knowledge gaps were identified during the investigation. Those need to be addressed in order to improve on the model calibration and further modelling predictions. In general, there is a lack of hydrogeological parameters to characterise the aquifers in the immediate vicinity of the TSF's. The following actions can be adopted to improve on the knowledge gaps:

- Establish a groundwater monitoring program at each of the various Harmony Sites.
- Allow for the monthly measurements of water levels in the observation boreholes.
- Allow for the analysis of water samples for a full suite of inorganic constituents on at least a quarterly basis.
- Areas lacking monitoring boreholes should be identified and boreholes drilled in those areas.
- Such newly drilled boreholes should become part of the Harmony groundwater monitoring systems.

There is further a lack of information with regards to the potential contaminant sources. The following actions can be adopted to improve on the knowledge gaps:

- Conduct a source quantification investigation. This should involve the necessary investigations to provide answers pertaining to the following uncertainties:
    1. The identification of all of the potential sources which may have acted on the system since the existence of the Facilities (TSF's RWD's, WRD's etc.).
    2. The spatial extent of these sources over time.
    3. The concentration of these sources over time.
    4. The seepage rates of these sources over time.
- Source depletion estimation must be conducted for each contaminated source in the form of source decay curves. This can be supplied to the mass transport model in order to get a more accurate representation of the development of the pollution plumes over time.
- Finally, the FEFLOW model developed during this investigation for Harmony should be utilized on a continuous basis to further improve the understanding of flow and transport mechanisms as well as to aid with any management decisions.

12 References

Bear, J. and Verruijt, A., 1992. Modelling Groundwater Flow and Pollution. D. Reidel publishing Company.

Diersch, H-J, 1979. FEFLOW. Interactive, Graphics-based Finite-Element Simulation System for Modeling Groundwater Flow, Contaminant Mass and Heat Transport Processes. WASY Institute for Water Resources Planning and Systems Research Ltd. Berlin.

Golder, 2008. Harmony Tailings Remining EIA-Phase I Groundwater Report. Report No: 8788/11368/16/G

Spitz, K., and Moreno, J., 1996. A practical guide to groundwater and solute transport modelling. John Wiley and Sons, Inc.

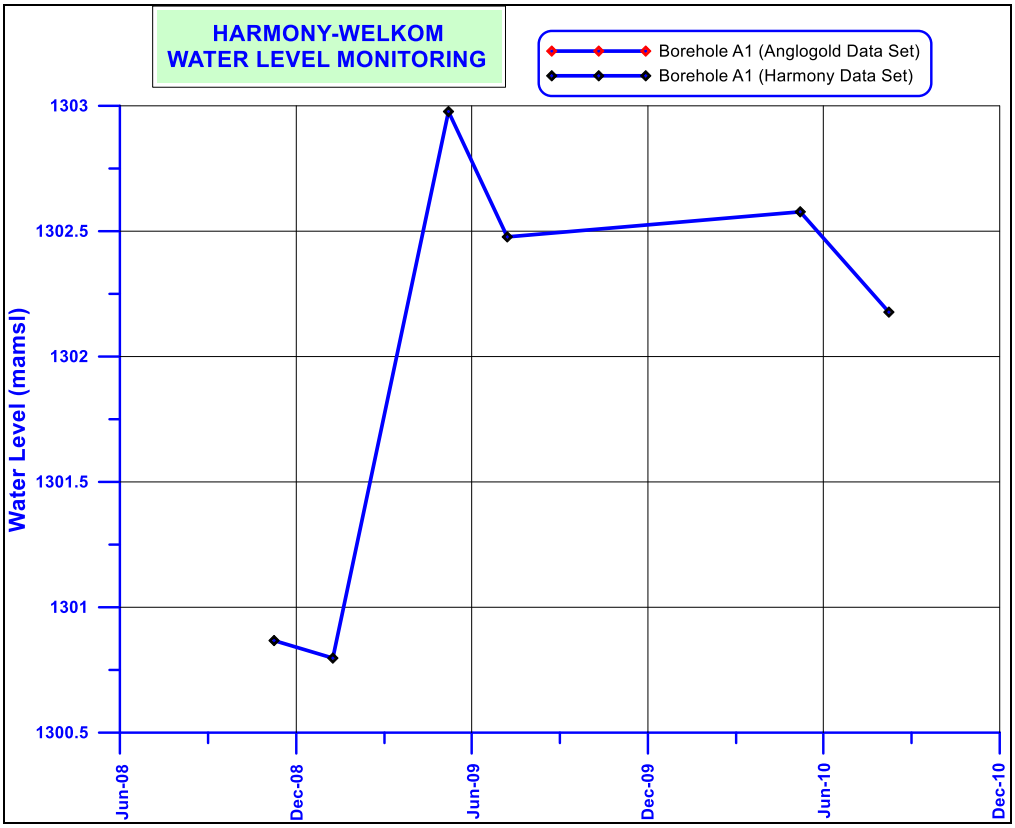
Surfer version 9.0, 2008. Golden Software, Golden, Colorado, USA.

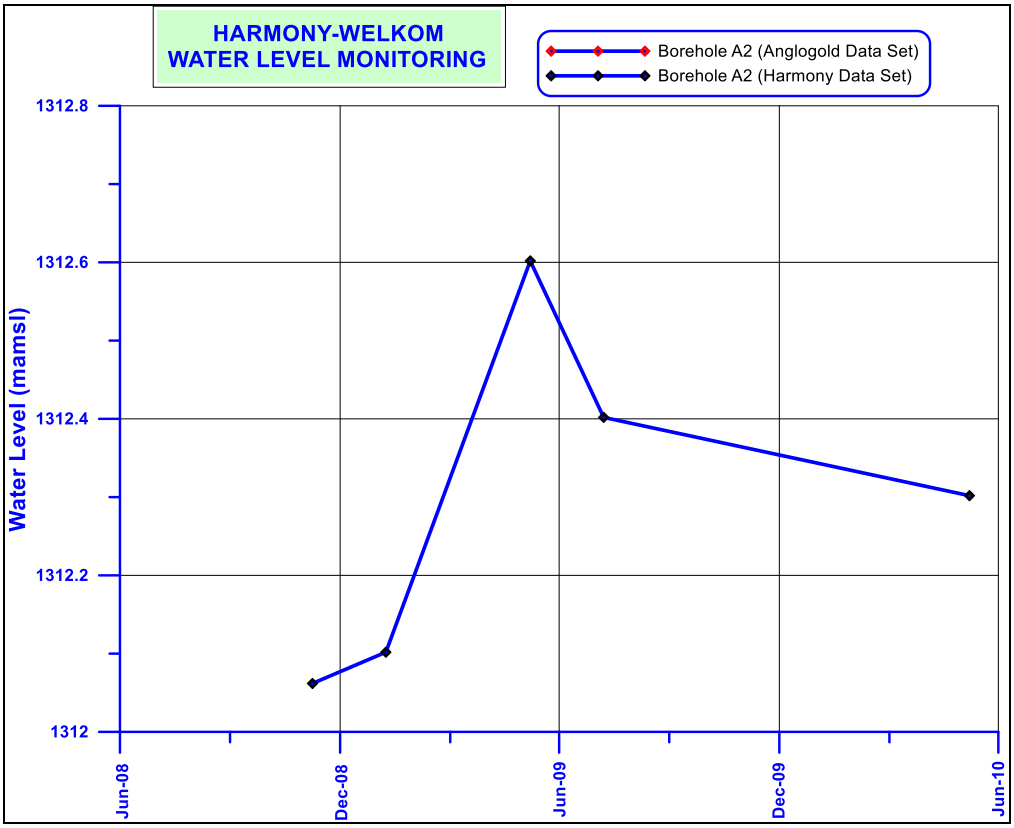
Vegter, J.R., 1995. An Explanation of a set of National Groundwater Maps. Water Research Commission Report No. TT74/95.

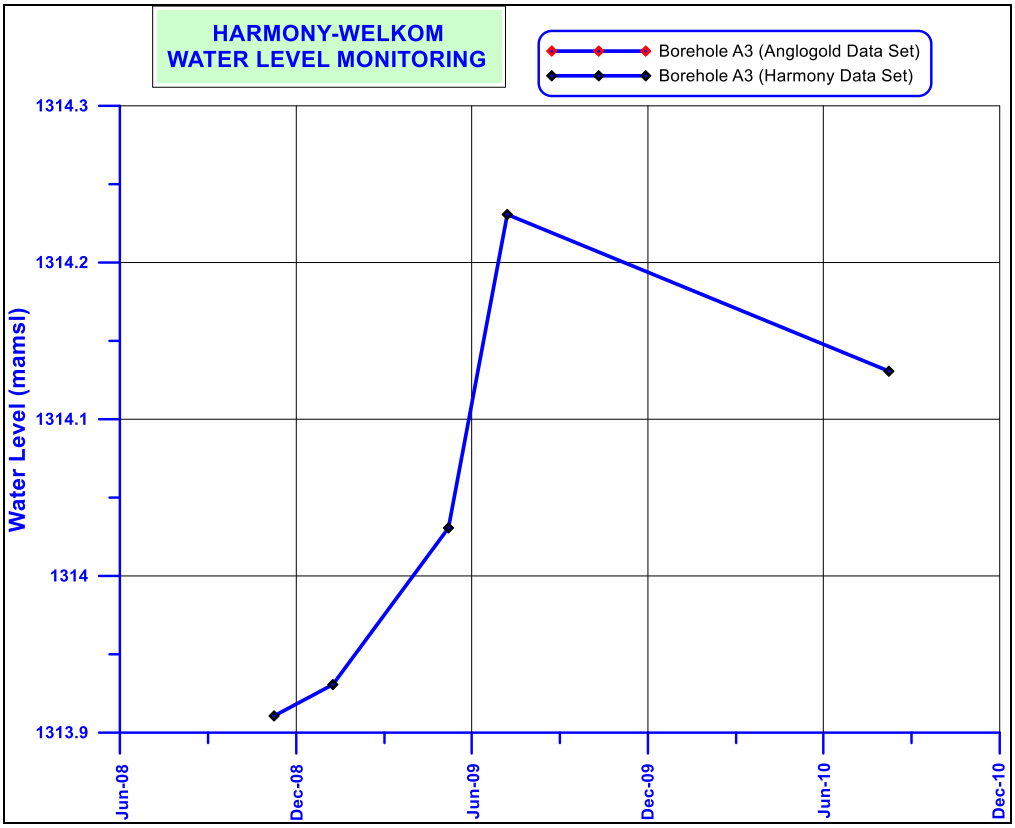
WRC, 1998. Quality of domestic water supplies Vol 1: assessment guide rep. No. tt101/98 2nd edition.

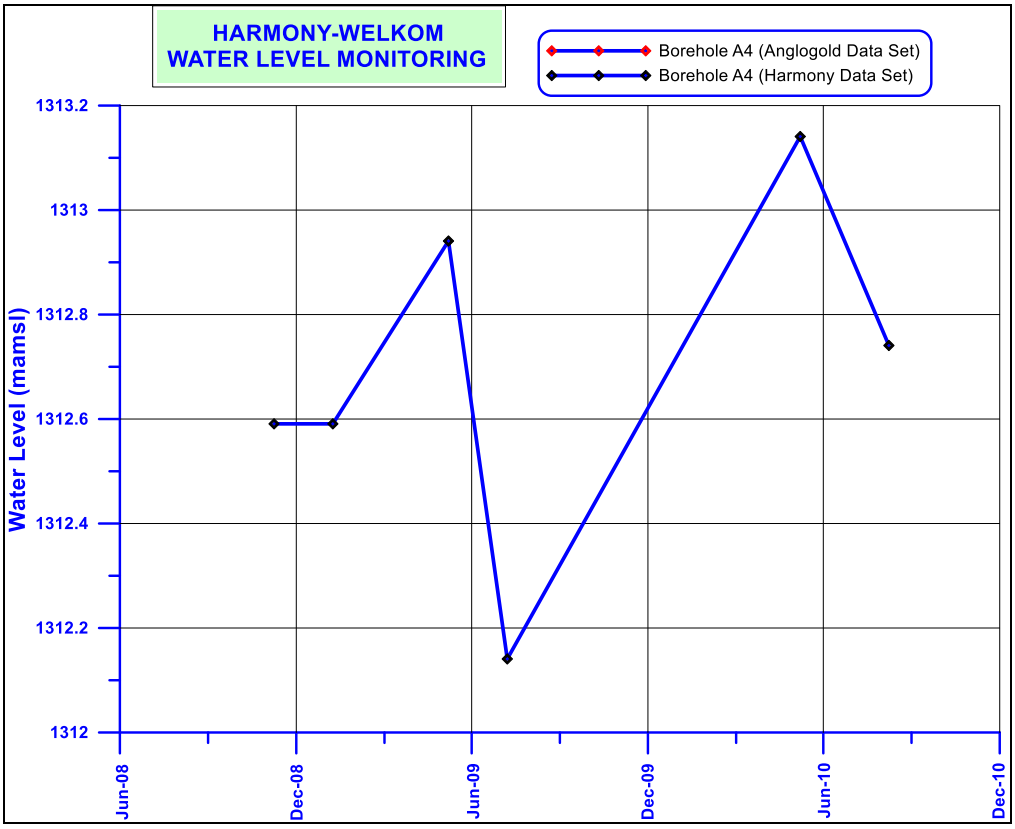


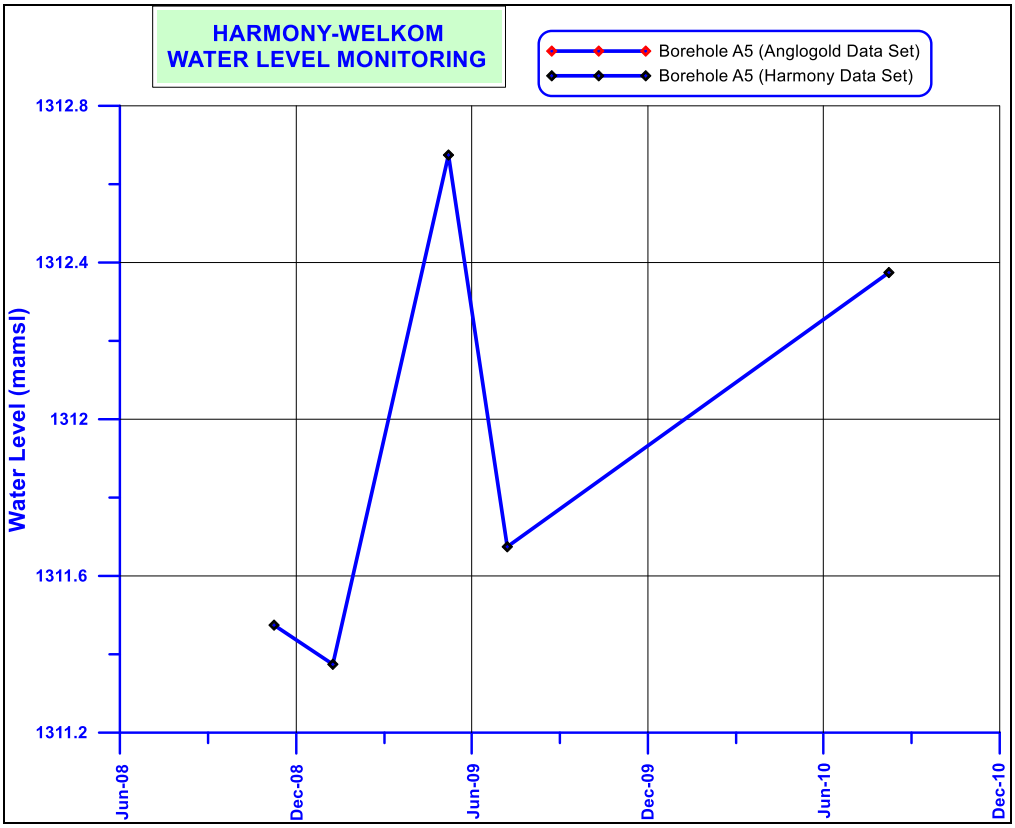
Appendix I
Welkom Harmony - Groundwater Level Fluctuations

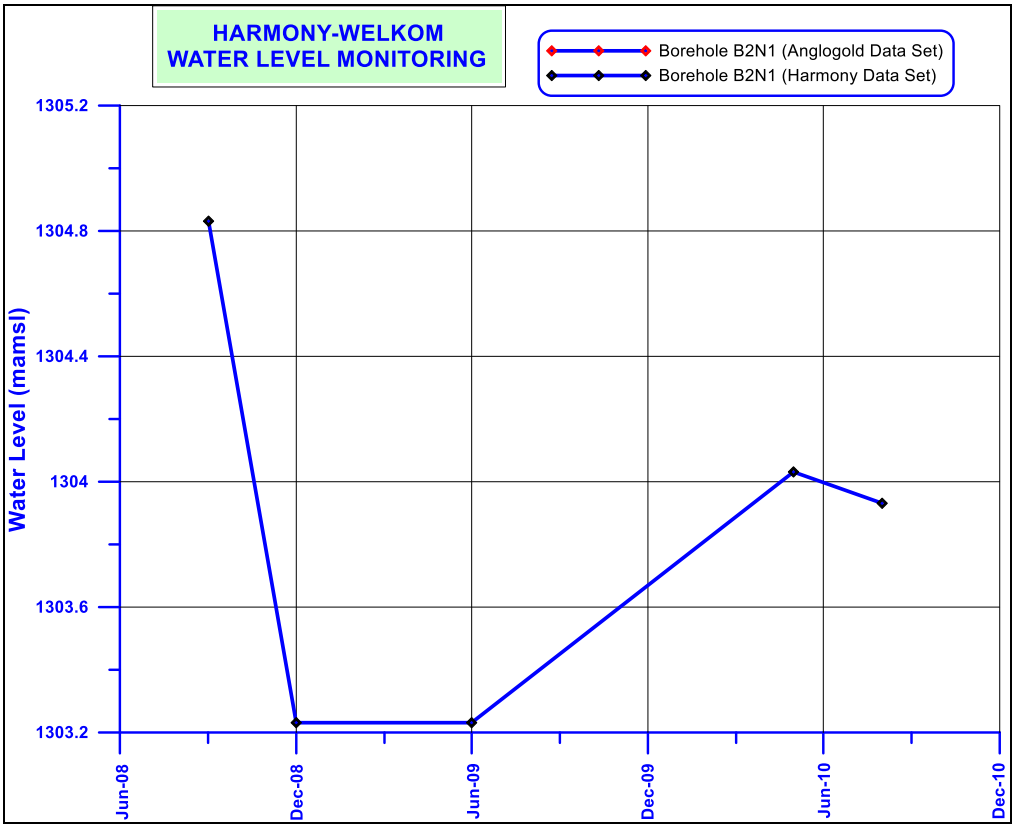

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole A1 (Anglogold Data Set)
Borehole A1 (Harmony Data Set)
Water Level (mamsl)
1303
1302.5
1302
1301.5
1301
1300.5
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10

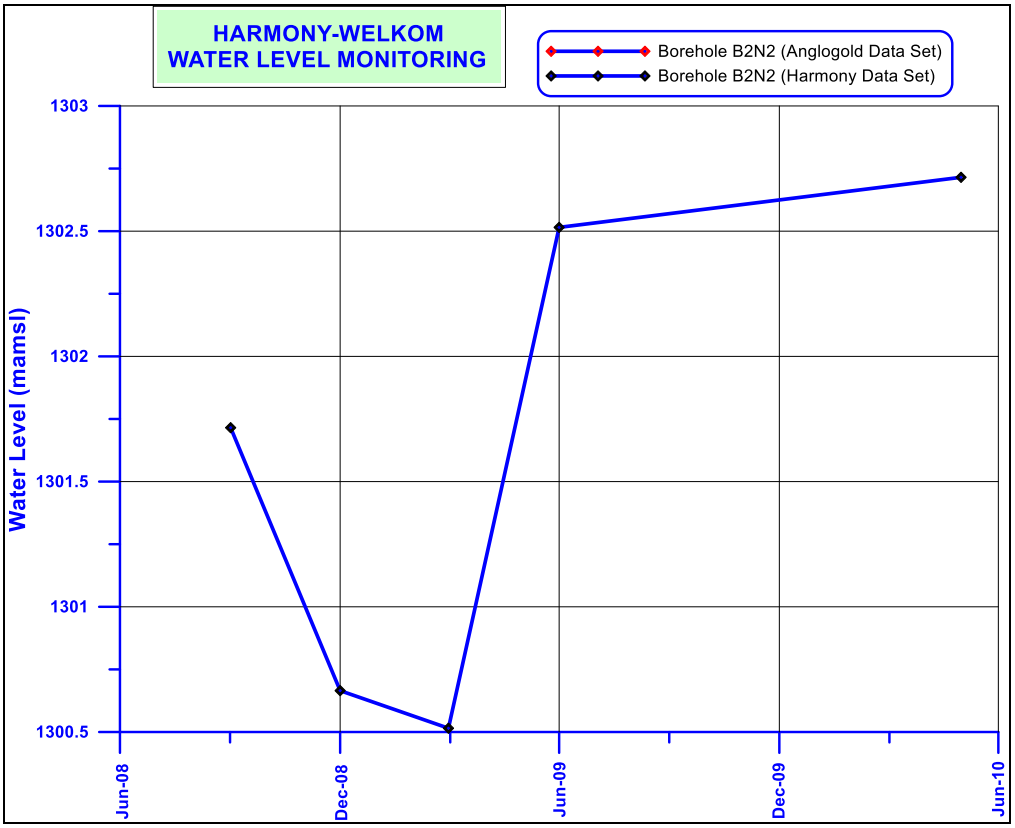

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole A2 (Anglogold Data Set)
Borehole A2 (Harmony Data Set)
Water Level (mamsl)
1312.8
1312.6
1312.4
1312.2
1312
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10

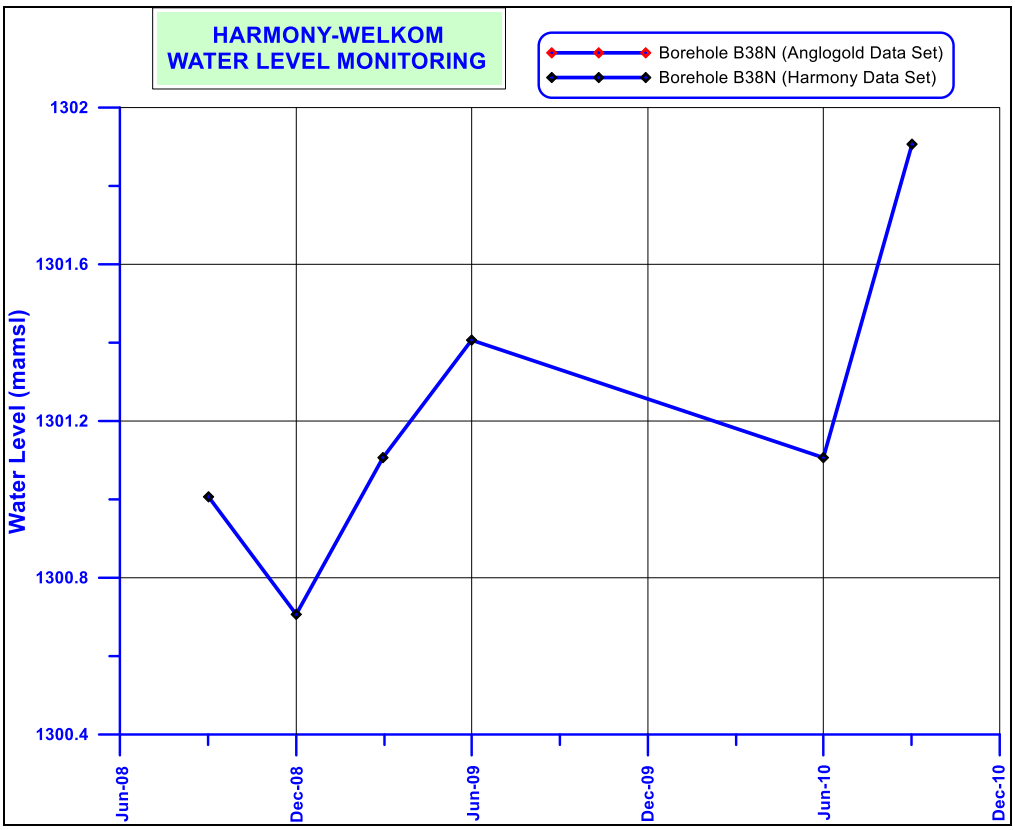

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole A3 (Anglogold Data Set)
Borehole A3 (Harmony Data Set)
Water Level (mamsl)
1314.3
1314.2
1314.1
1314
1313.9
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10

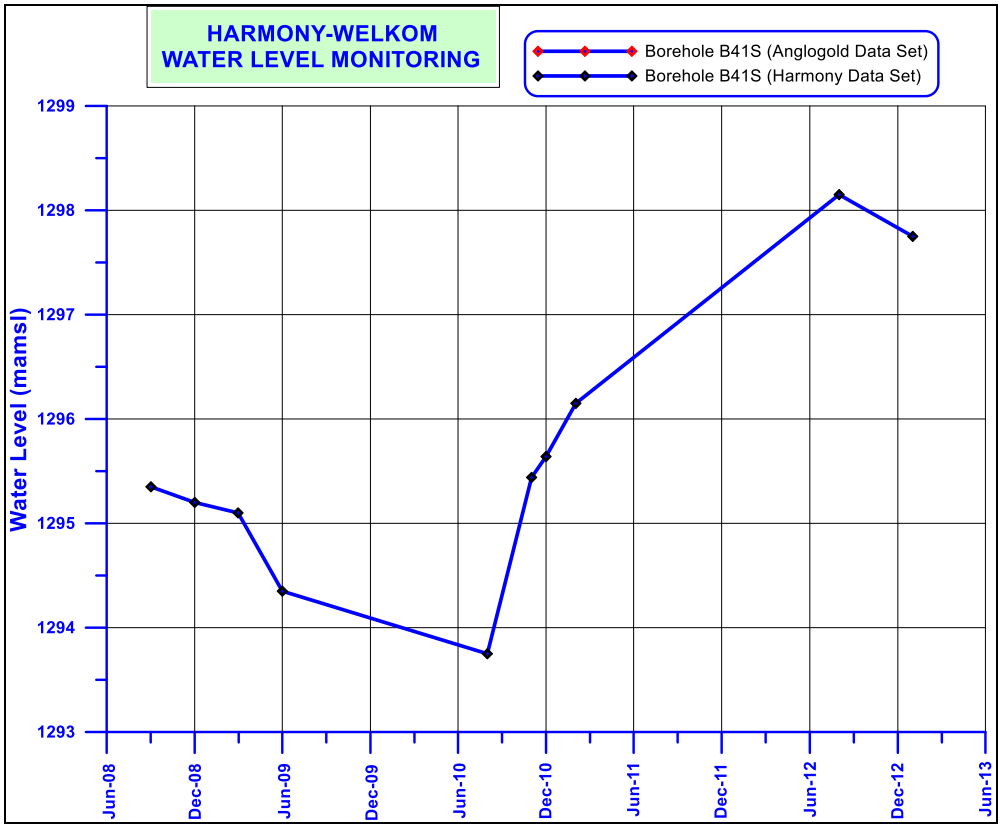

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole A4 (Anglogold Data Set)
Borehole A4 (Harmony Data Set)
Water Level (mamsl)
1313.2
1313
1312.8
1312.6
1312.4
1312.2
1312
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10

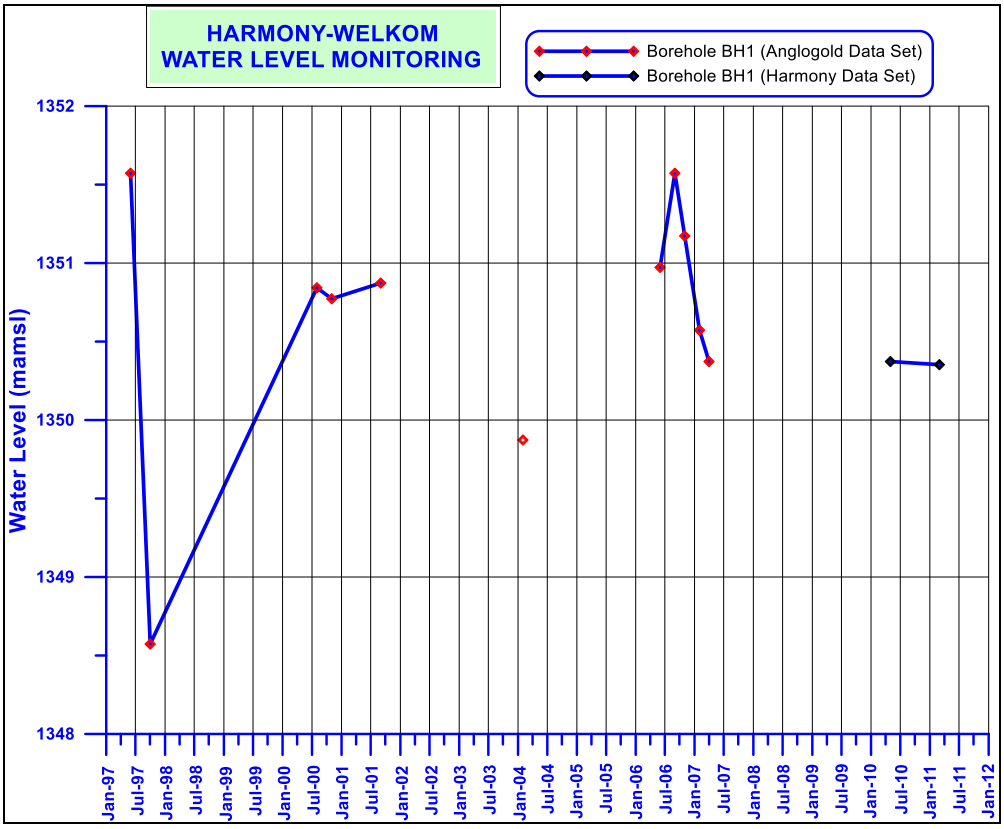

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole A5 (Anglogold Data Set)
Borehole A5 (Harmony Data Set)
Water Level (mamsl)
1312.8
1312.4
1312
1311.6
1311.2
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10

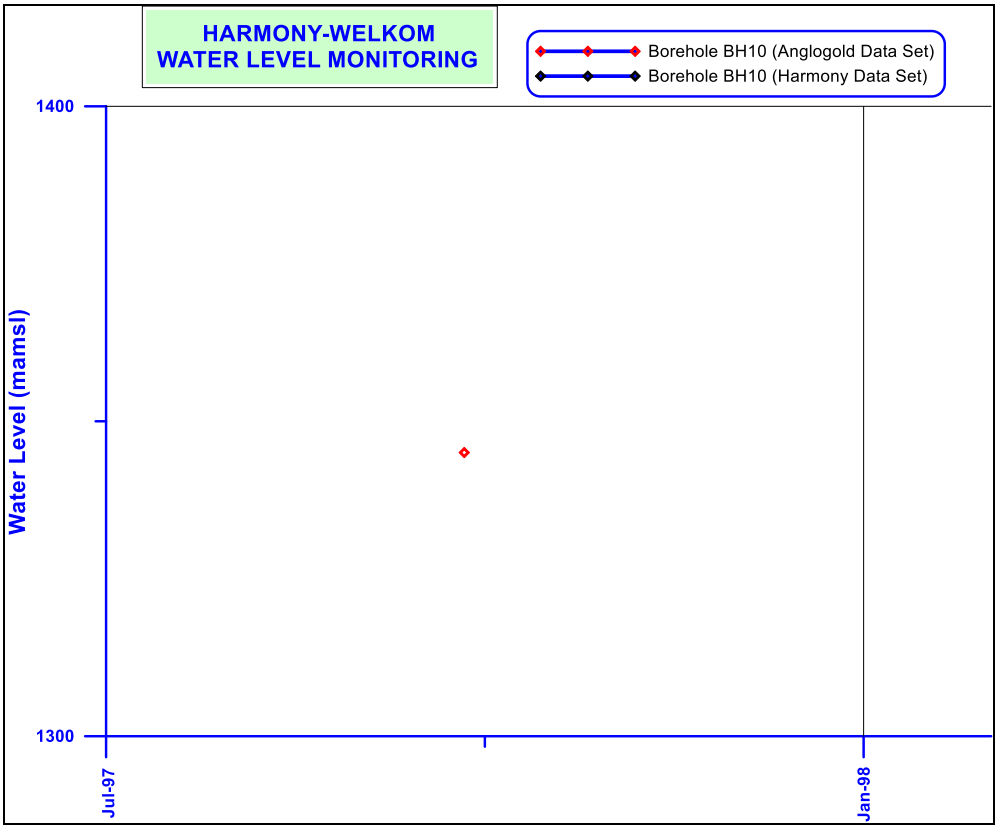

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole B2N1 (Anglogold Data Set)
Borehole B2N1 (Harmony Data Set)
Water Level (mamsl)
1305.2
1304.8
1304.4
1304
1303.6
1303.2
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10

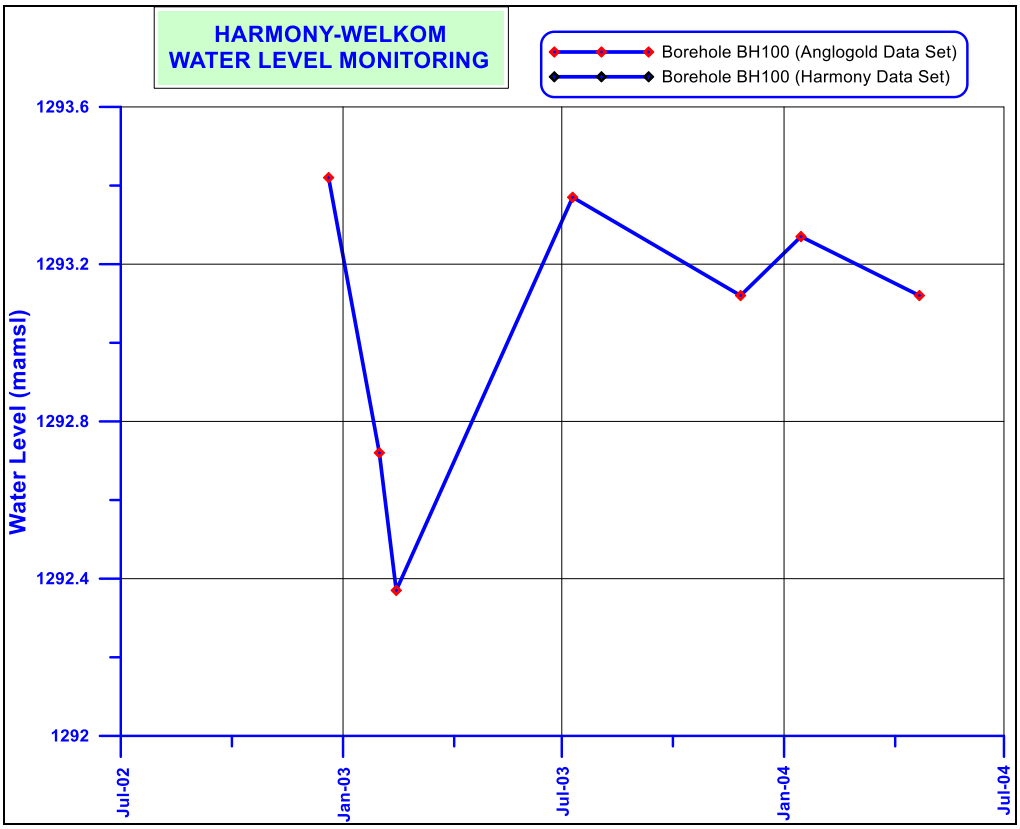

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole B2N2 (Anglogold Data Set)
Borehole B2N2 (Harmony Data Set)
Water Level (mamsl)
1303
1302.5
1302
1301.5
1301
1300.5
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10

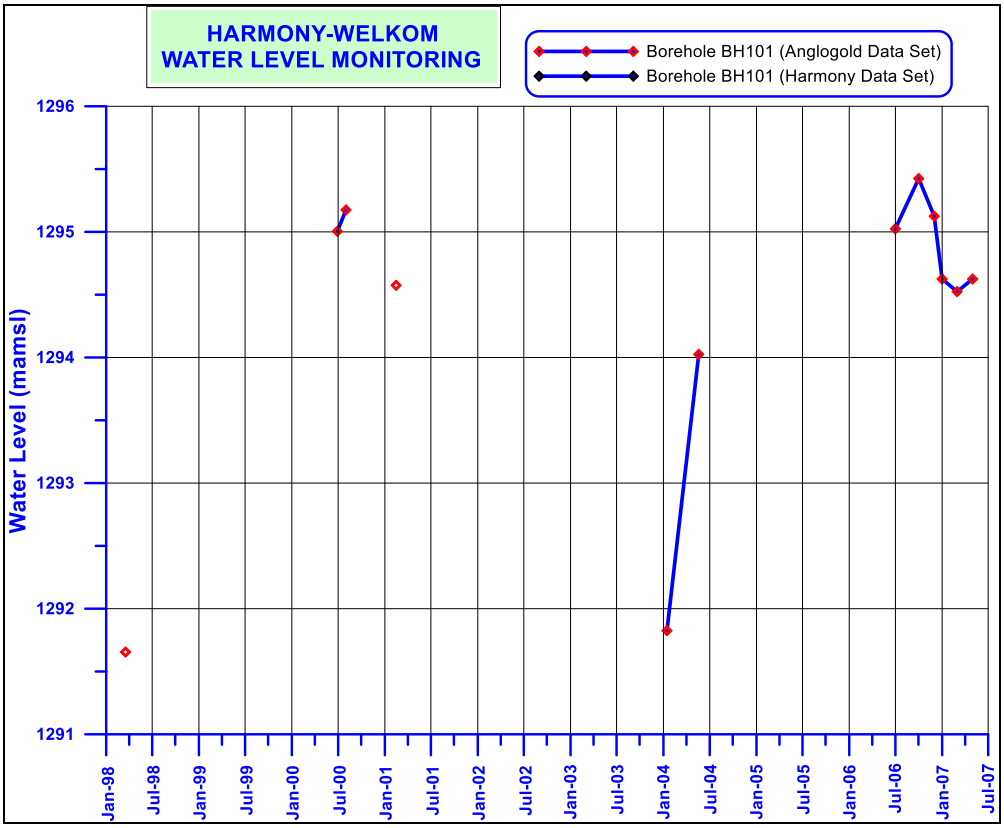

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole B38N (Anglogold Data Set)
Borehole B38N (Harmony Data Set)
Water Level (mamsl)
1302
1301.6
1301.2
1300.8
1300.4
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10

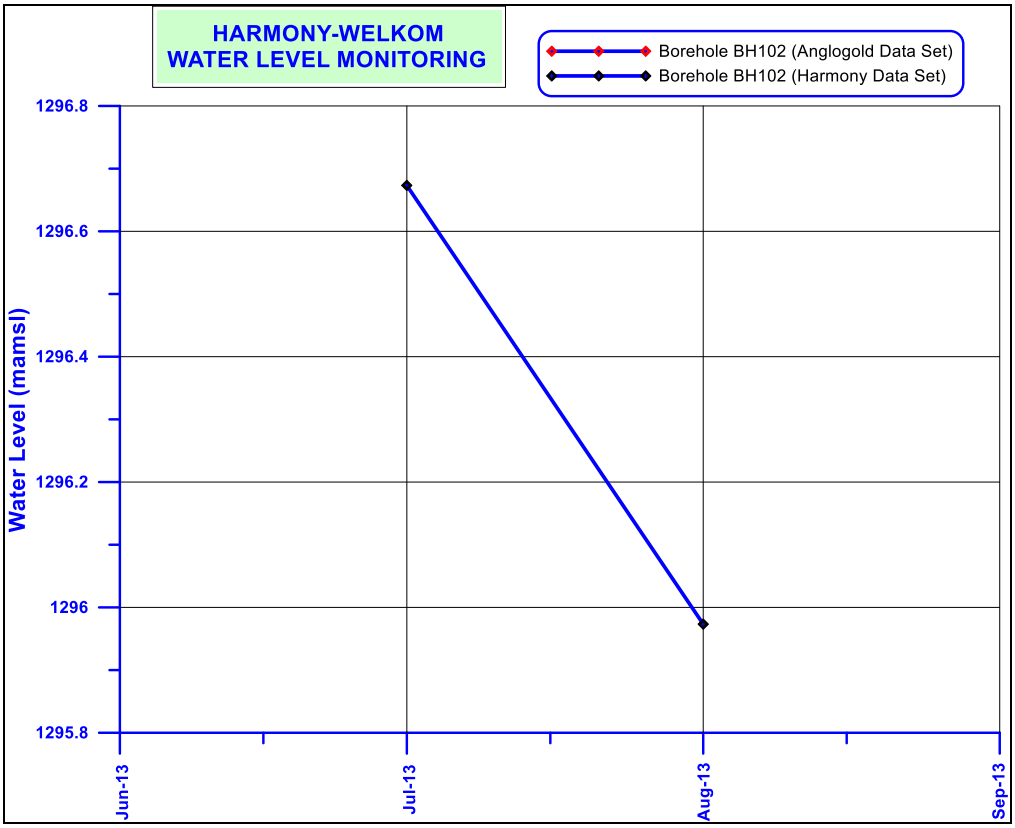

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole B41S (Anglogold Data Set)
Borehole B41S (Harmony Data Set)
Water Level (mamsl)
1299
1298
1297
1296
1295
1294
1293
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13

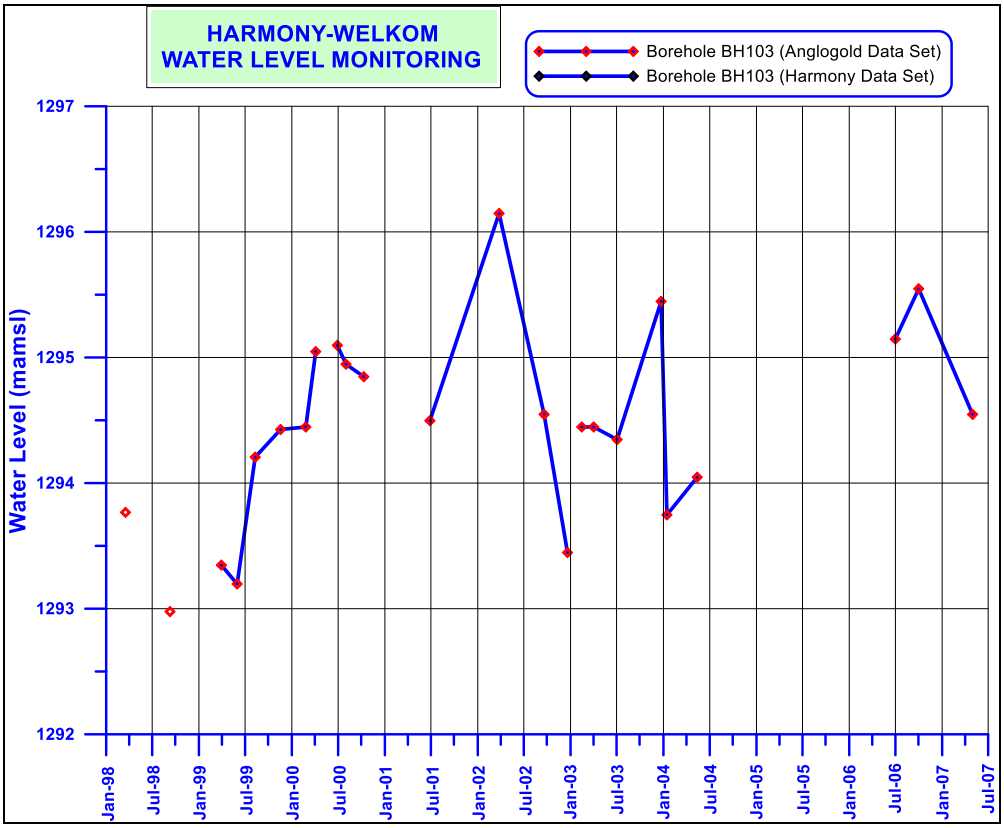

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH1 (Anglogold Data Set)
Borehole BH1 (Harmony Data Set)
Water Level (mamsl)
1352
1351
1350
1349
1348
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12

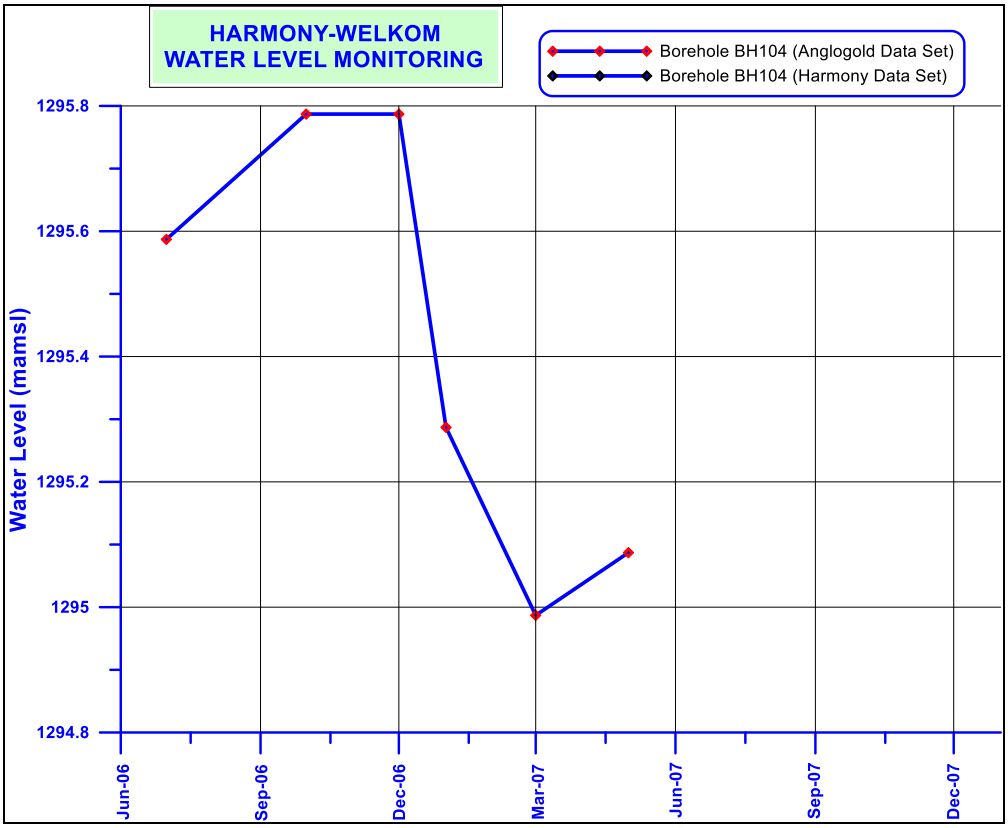

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH10 (Anglogold Data Set)
Borehole BH10 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jul-97
Jan-98

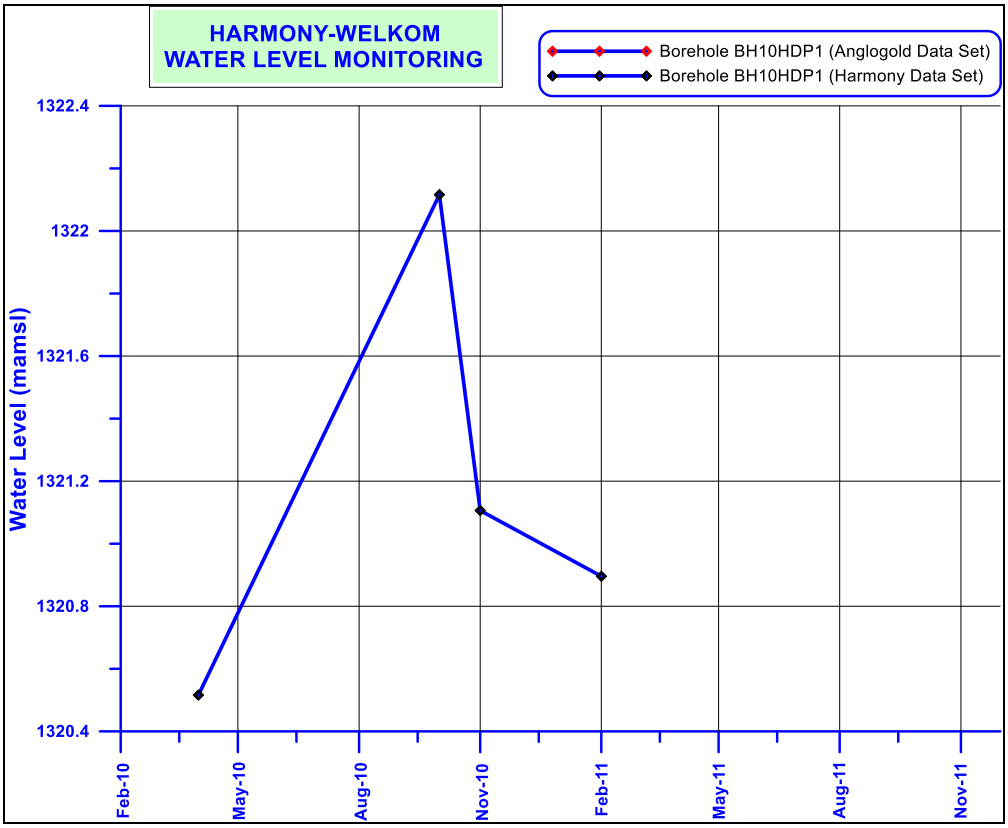

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH100 (Anglogold Data Set)
Borehole BH100 (Harmony Data Set)
Water Level (mamsl)
1293.6
1293.2
1292.8
1292.4
1292
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04

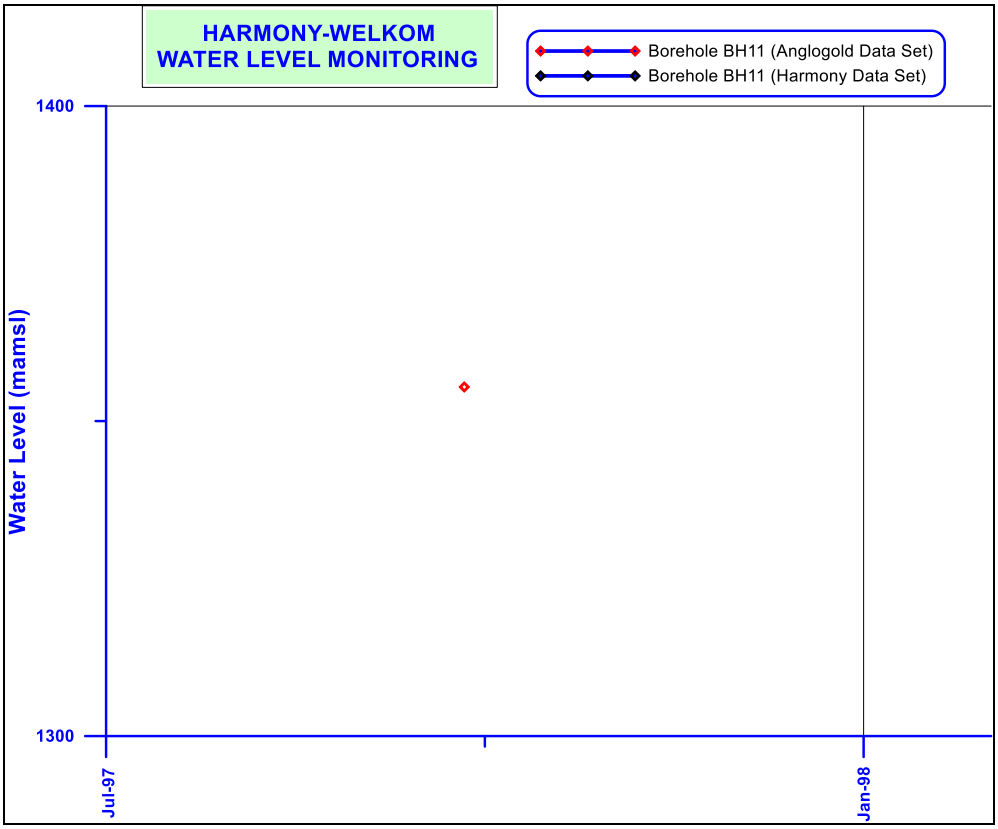

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH101 (Anglogold Data Set)
Borehole BH101 (Harmony Data Set)
Water Level (mamsl)
1296
1295
1294
1293
1292
1291
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

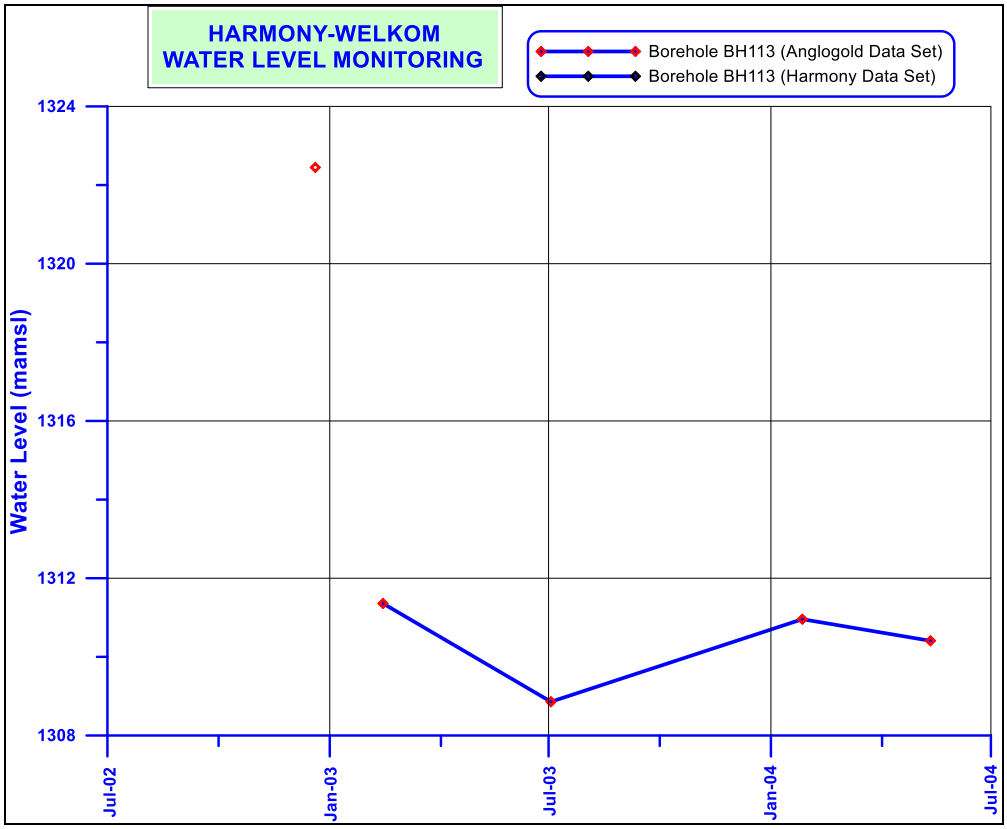

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH102 (Anglogold Data Set)
Borehole BH102 (Harmony Data Set)
Water Level (mamsl)
1296.8
1296.6
1296.4
1296.2
1296
1295.8
Jun-13
Jul-13
Aug-13
Sep-13

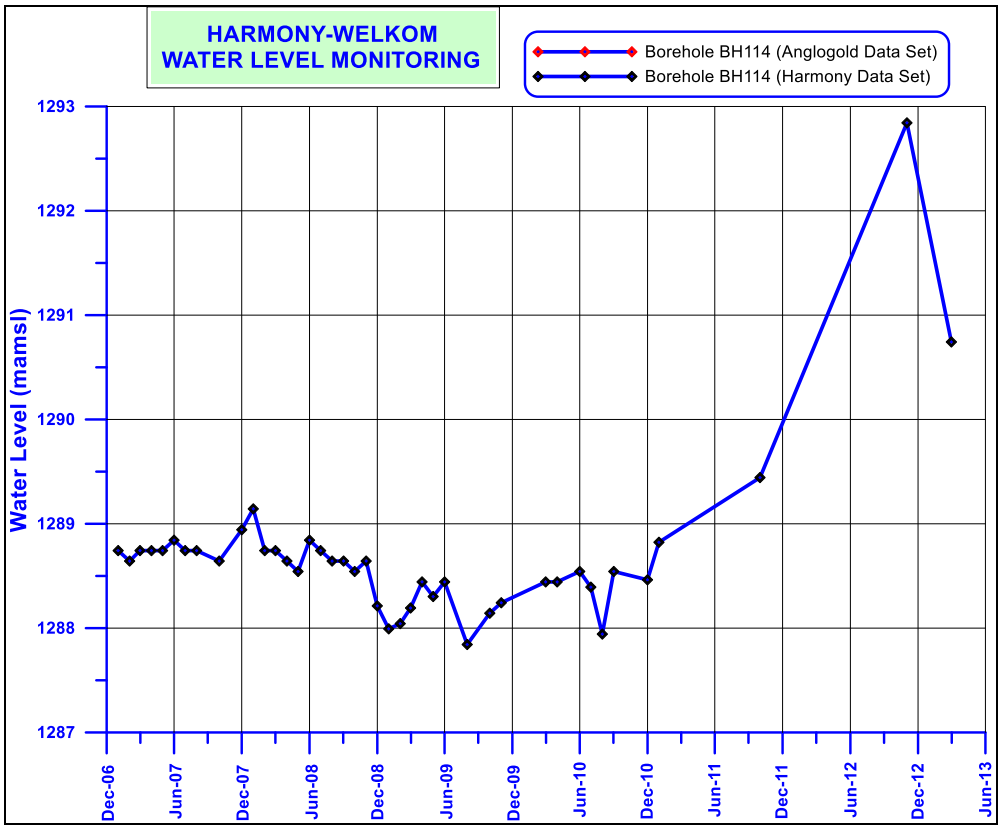

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH103 (Anglogold Data Set)
Borehole BH103 (Harmony Data Set)
Water Level (mamsl)
1297
1296
1295
1294
1293
1292
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

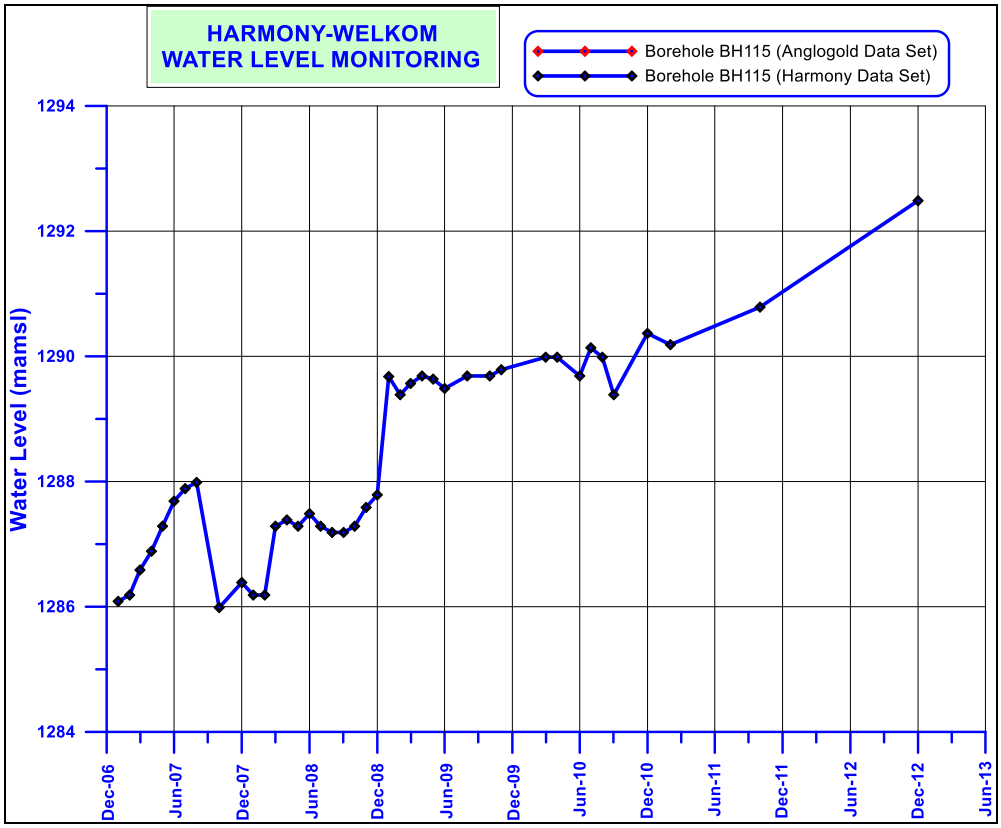

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH104 (Anglogold Data Set)
Borehole BH104 (Harmony Data Set)
Water Level (mamsl)
1295.8
1295.6
1295.4
1295.2
1295
1294.8
Jun-06
Sep-06
Dec-06
Mar-07
Jun-07
Sep-07
Dec-07

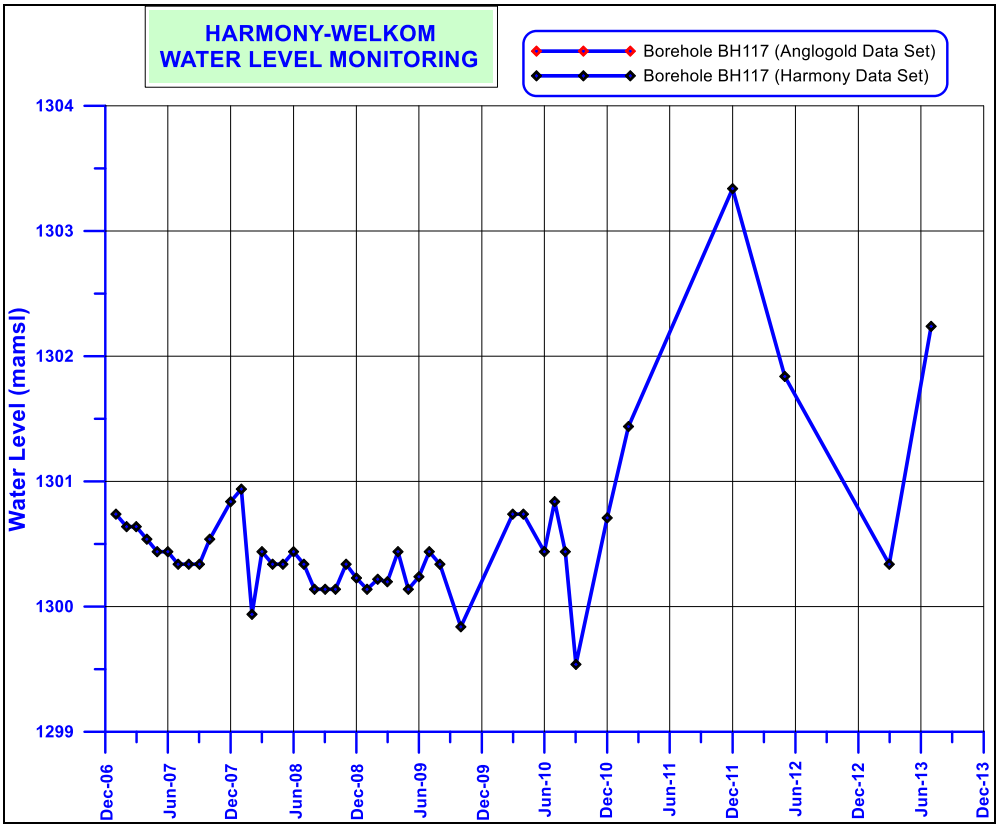

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH10HDP1 (Anglogold Data Set)
Borehole BH10HDP1 (Harmony Data Set)
Water Level (mamsl)
1322.4
1322
1321.6
1321.2
1320.8
1320.4
Feb-10
May-10
Aug-10
Nov-10
Feb-11
May-11
Aug-11
Nov-11

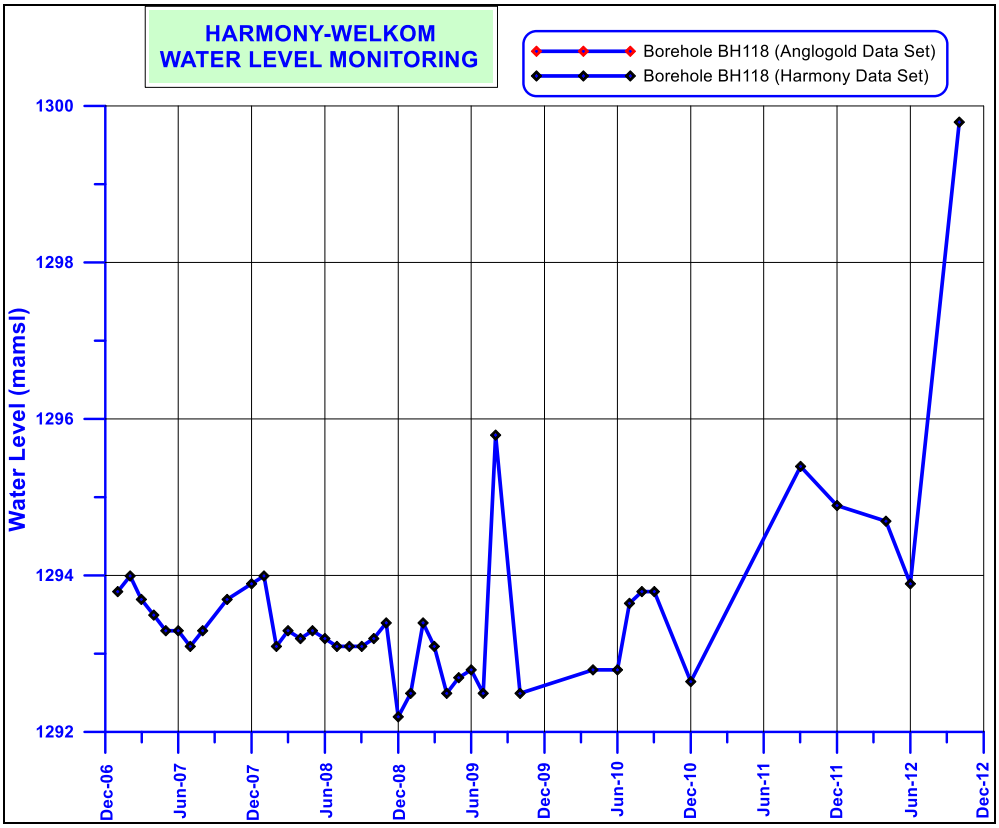

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH11 (Anglogold Data Set)
Borehole BH11 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jul-97
Jan-98

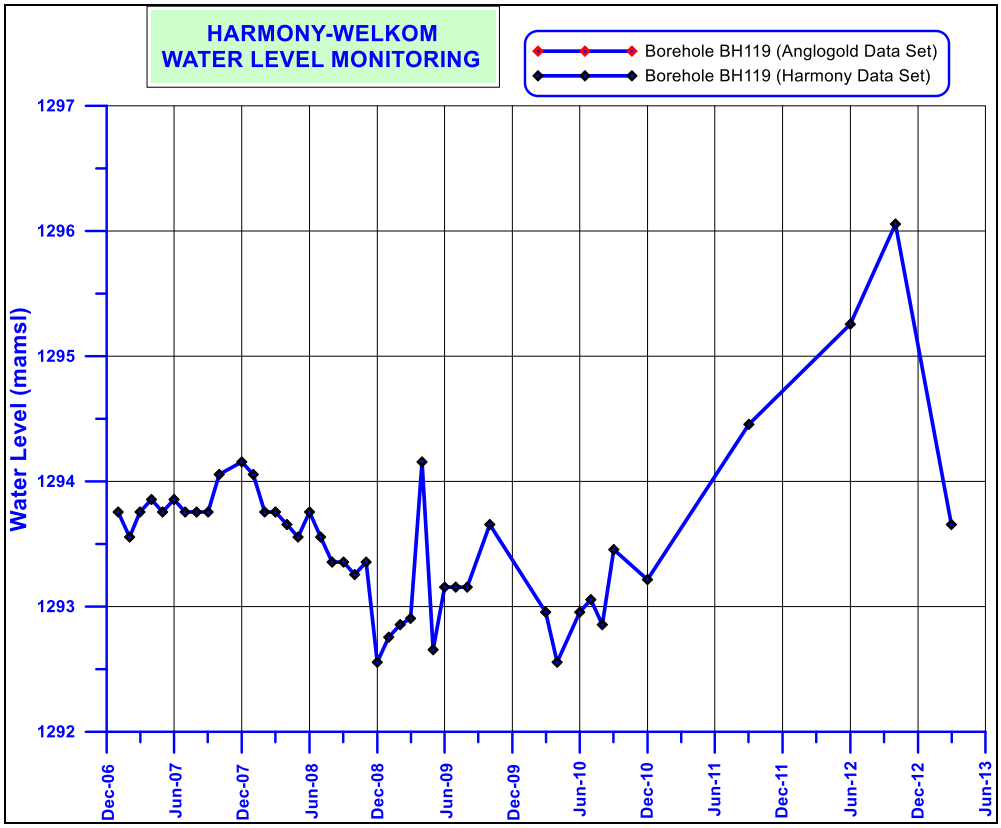

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH113 (Anglogold Data Set)
Borehole BH113 (Harmony Data Set)
Water Level (mamsl)
1324
1320
1316
1312
1308
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04

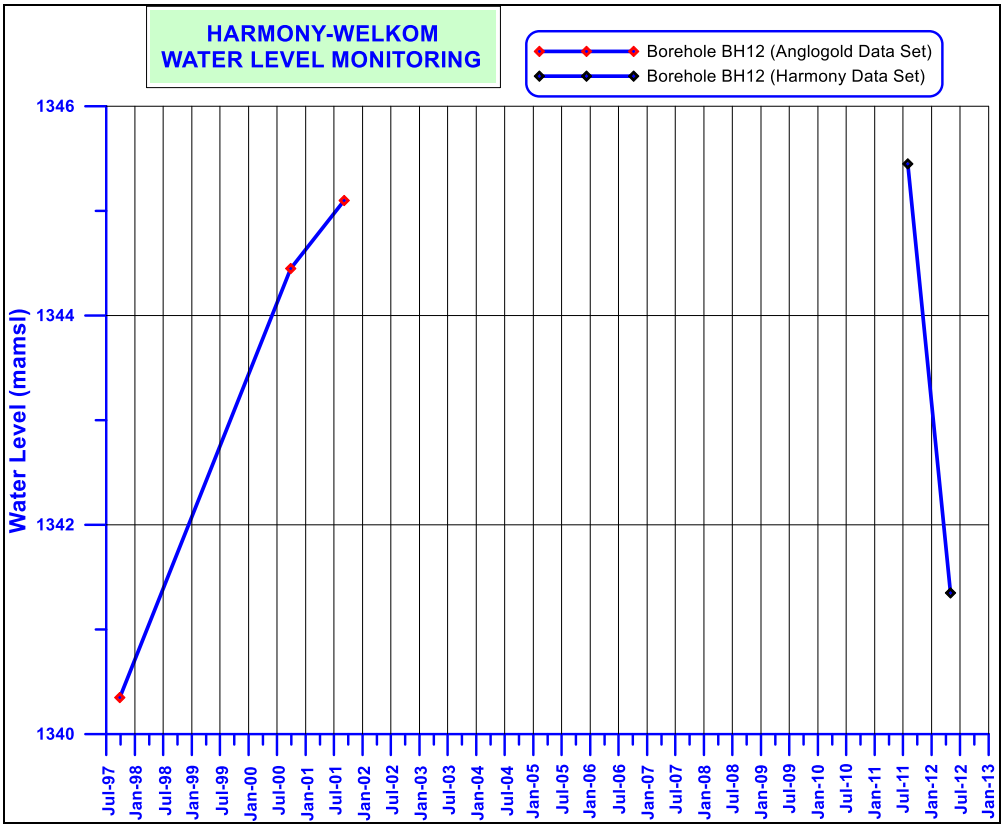

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH114 (Anglogold Data Set)
Borehole BH114 (Harmony Data Set)
Water Level (mamsl)
1293
1292
1291
1290
1289
1288
1287
Dec-06
Jun-07
Dec-07
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13

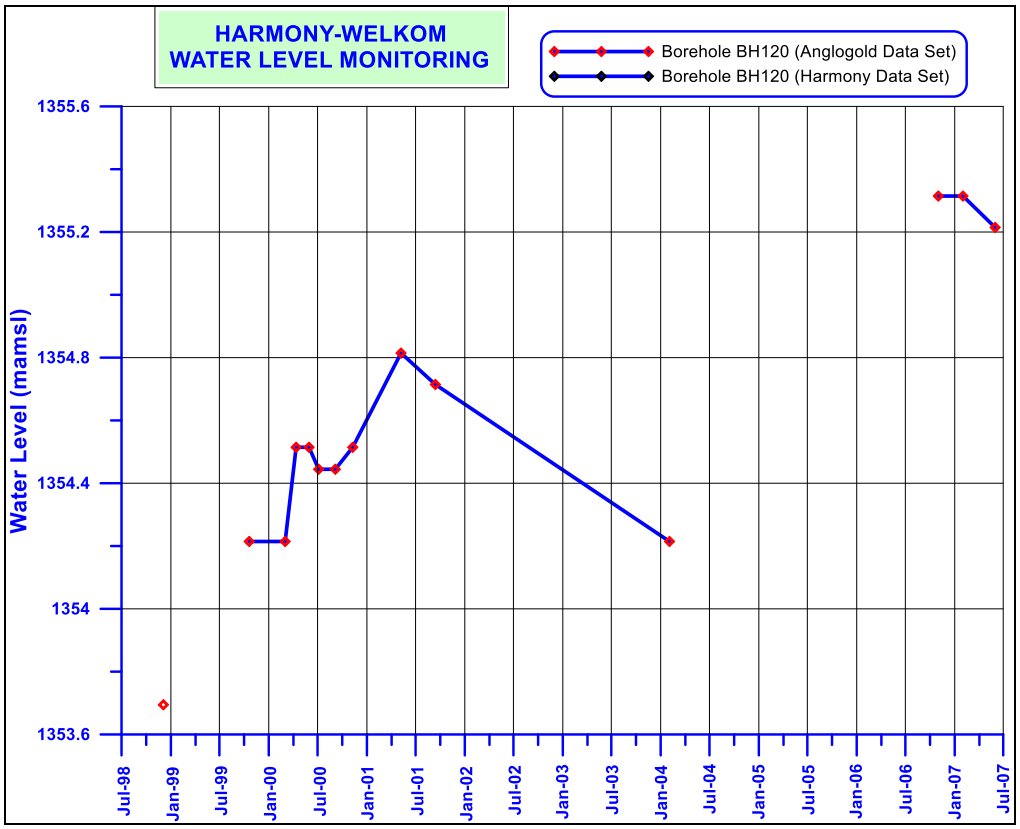

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH115 (Anglogold Data Set)
Borehole BH115 (Harmony Data Set)
Water Level (mamsl)
1294
1292
1290
1288
1286
1284
Dec-06
Jun-07
Dec-07
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13

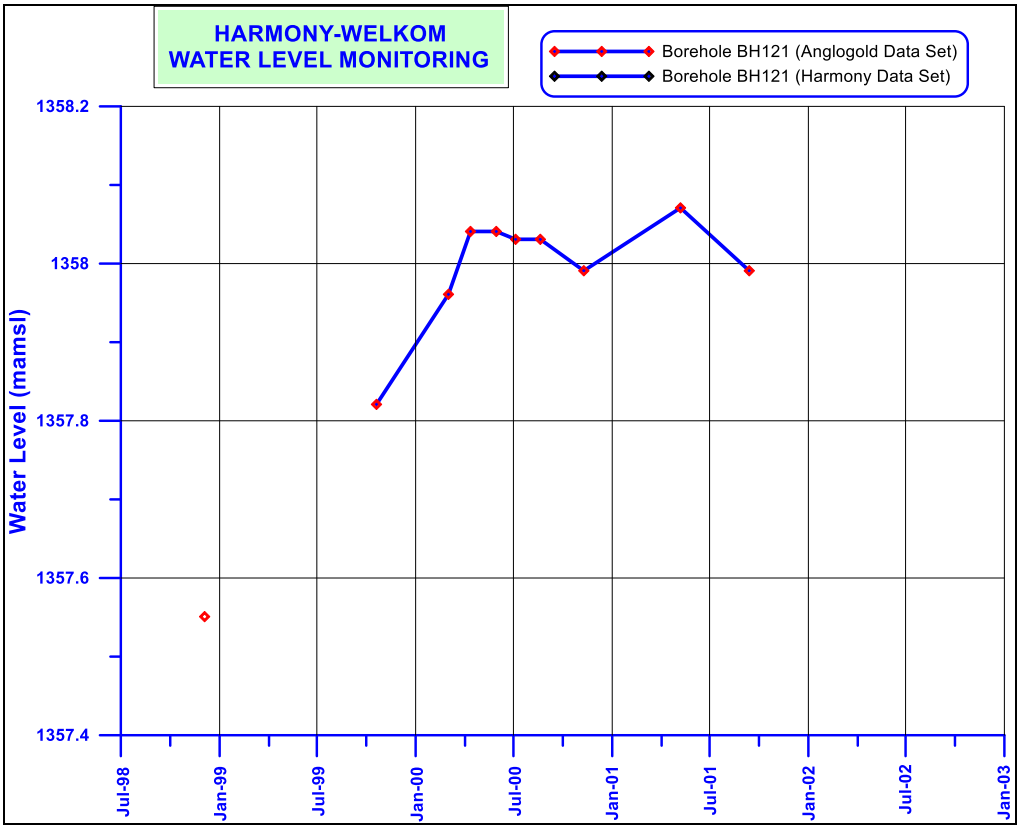

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH117 (Anglogold Data Set)
Borehole BH117 (Harmony Data Set)
Water Level (mamsl)
1304
1303
1302
1301
1300
1299
Dec-06
Jun-07
Dec-07
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13
Dec-13

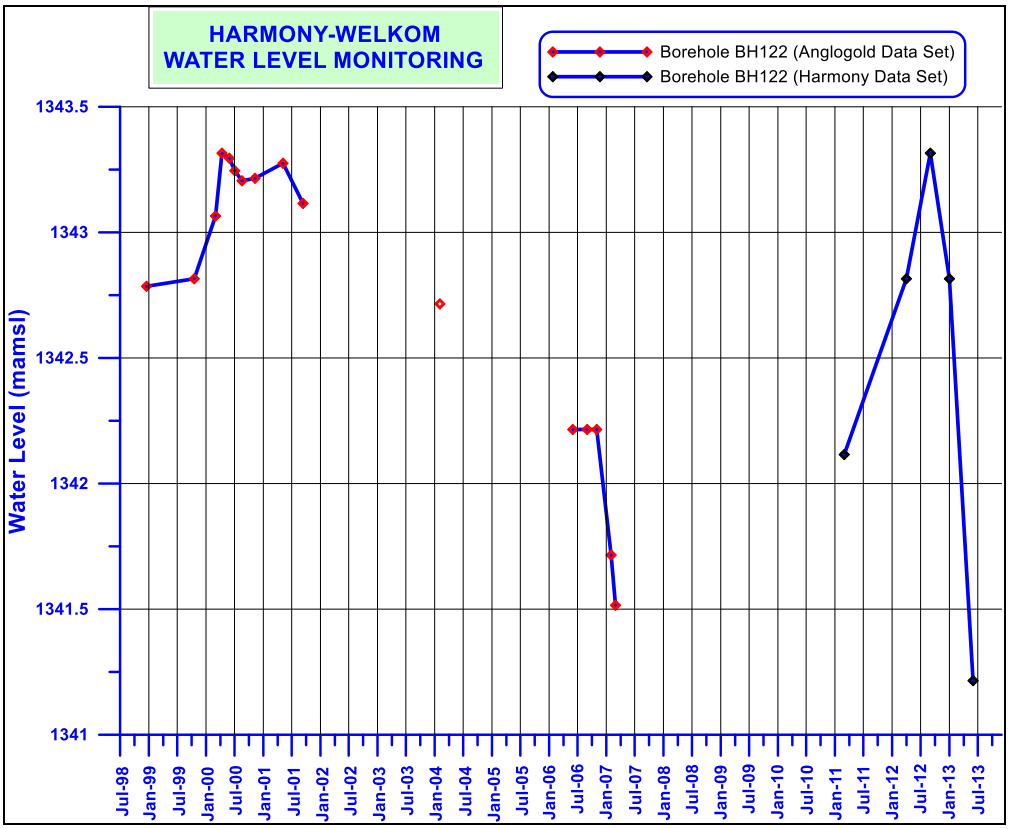

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH118 (Anglogold Data Set)
Borehole BH118 (Harmony Data Set)
Water Level (mamsl)
1300
1298
1296
1294
1292
Dec-06
Jun-07
Dec-07
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12

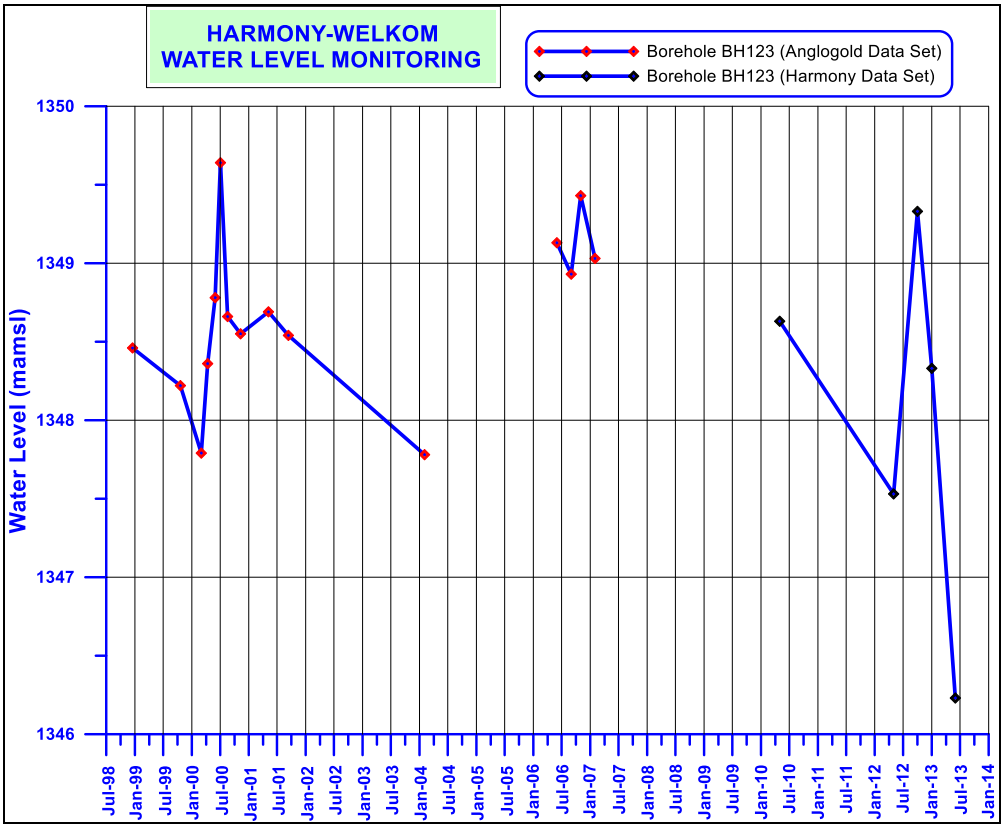

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH119 (Anglogold Data Set)
Borehole BH119 (Harmony Data Set)
Water Level (mamsl)
1297
1296
1295
1294
1293
1292
Dec-06
Jun-07
Dec-07
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13

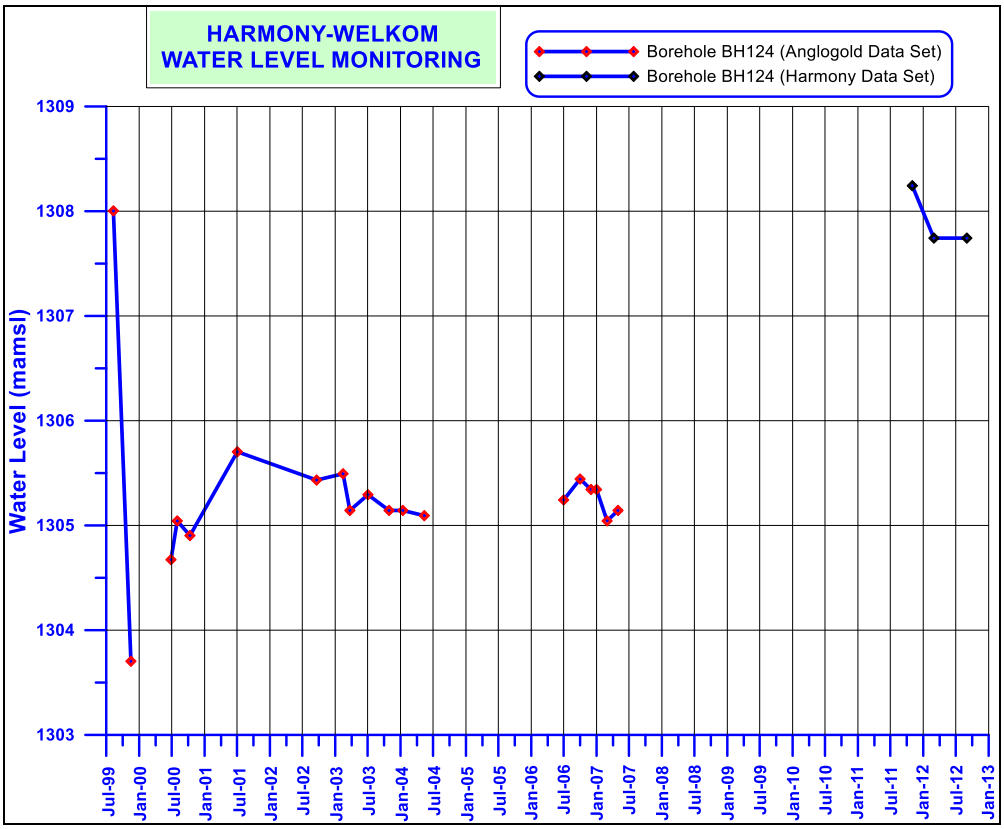

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH12 (Anglogold Data Set)
Borehole BH12 (Harmony Data Set)
Water Level (mamsl)
1346
1344
1342
1340
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13

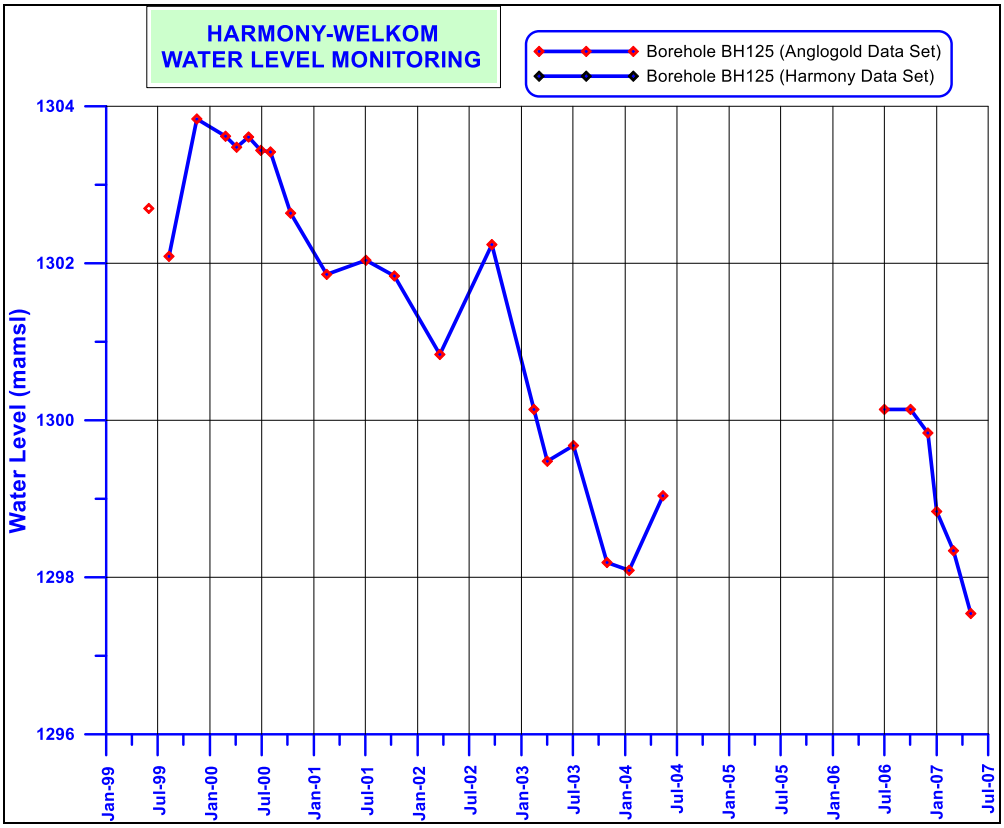

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH120 (Anglogold Data Set)
Borehole BH120 (Harmony Data Set)
Water Level (mamsl)
1355.6
1355.2
1354.8
1354.4
1354
1353.6
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

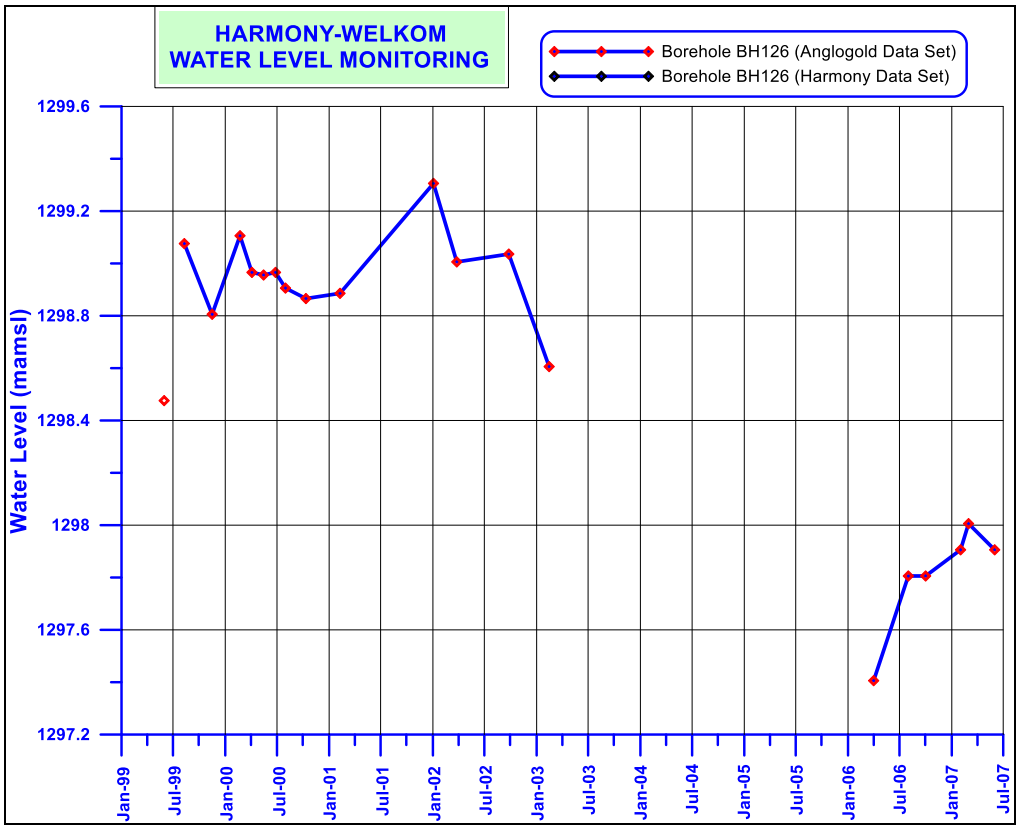

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH121 (Anglogold Data Set)
Borehole BH121 (Harmony Data Set)
Water Level (mamsl)
1358.2
1358
1357.8
1357.6
1357.4
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03

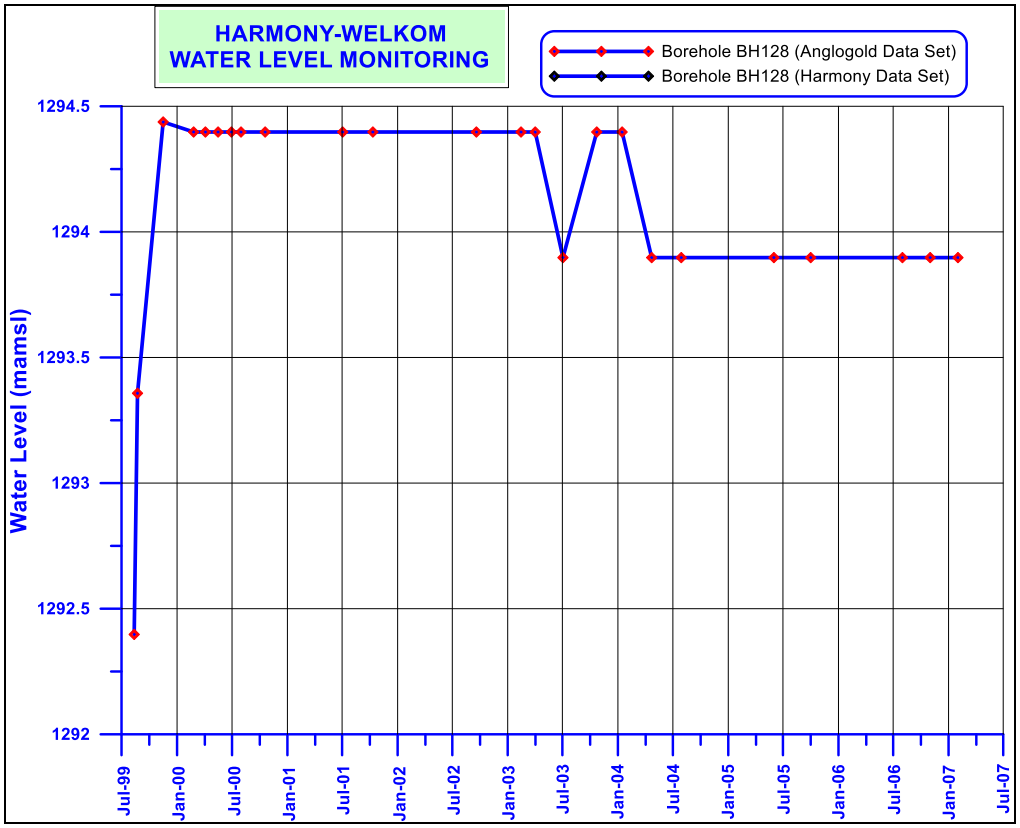

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH122 (Anglogold Data Set)
Borehole BH122 (Harmony Data Set)
Water Level (mamsl)
1343.5
1343
1342.5
1342
1341.5
1341
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13

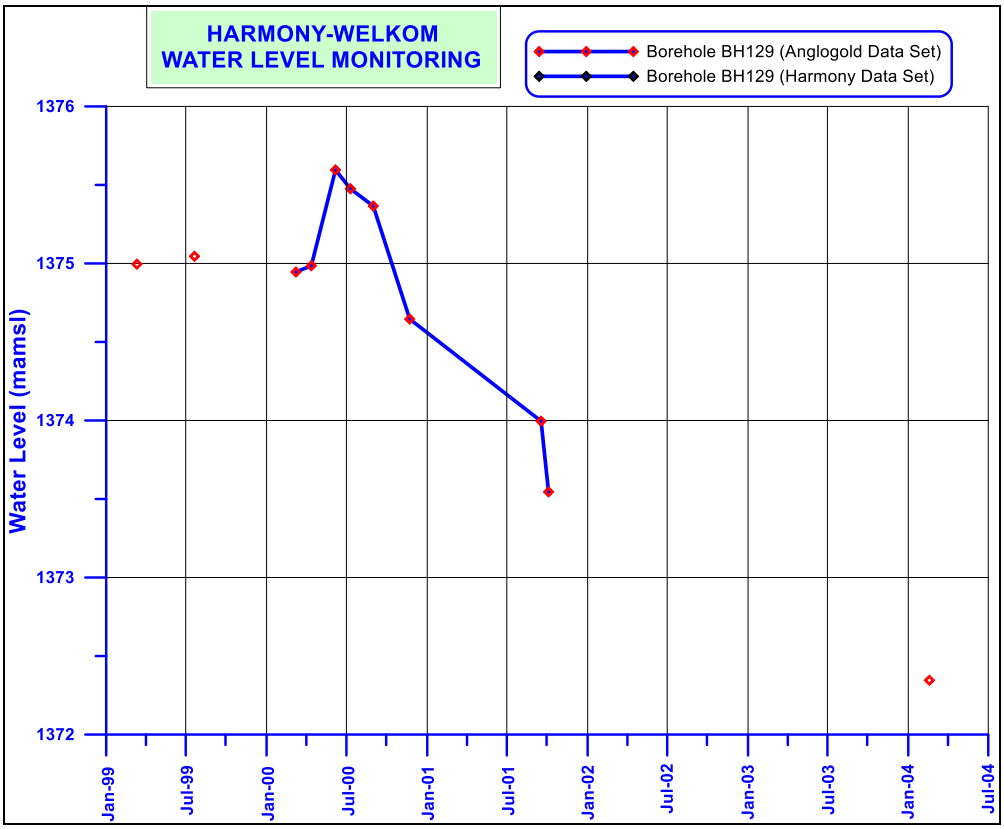

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH123 (Anglogold Data Set)
Borehole BH123 (Harmony Data Set)
Water Level (mamsl)
1350
1349
1348
1347
1346
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

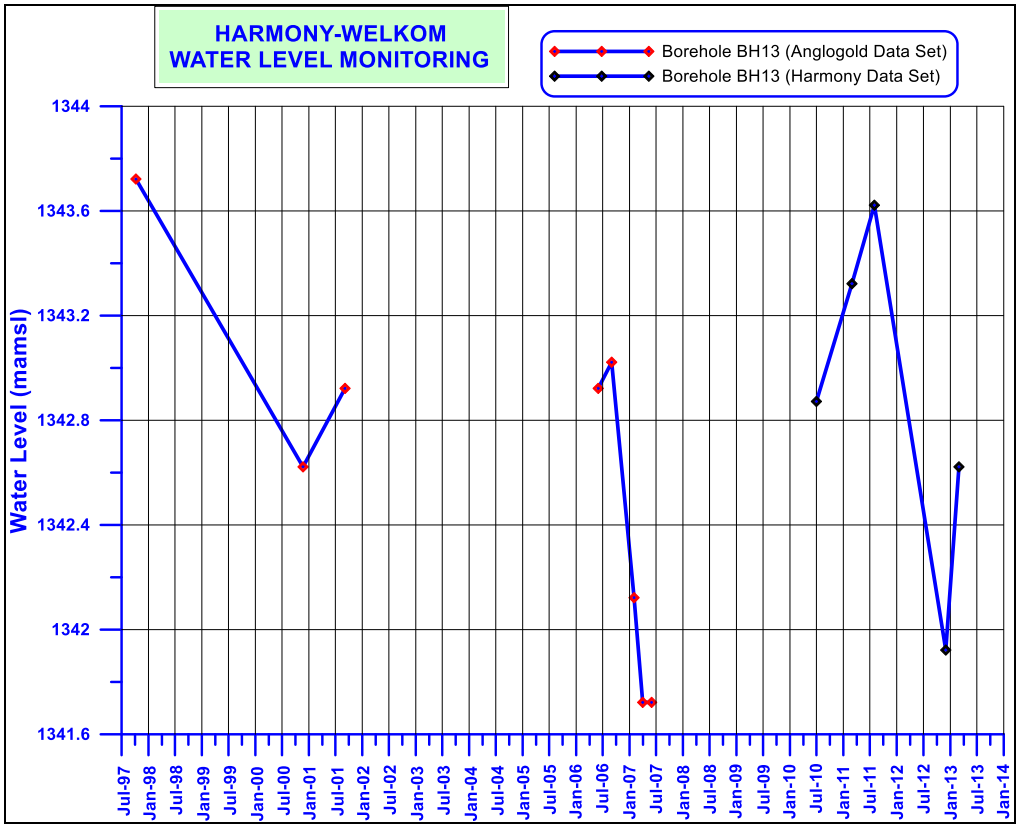

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH124 (Anglogold Data Set)
Borehole BH124 (Harmony Data Set)
Water Level (mamsl)
1309
1308
1307
1306
1305
1304
1303
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13

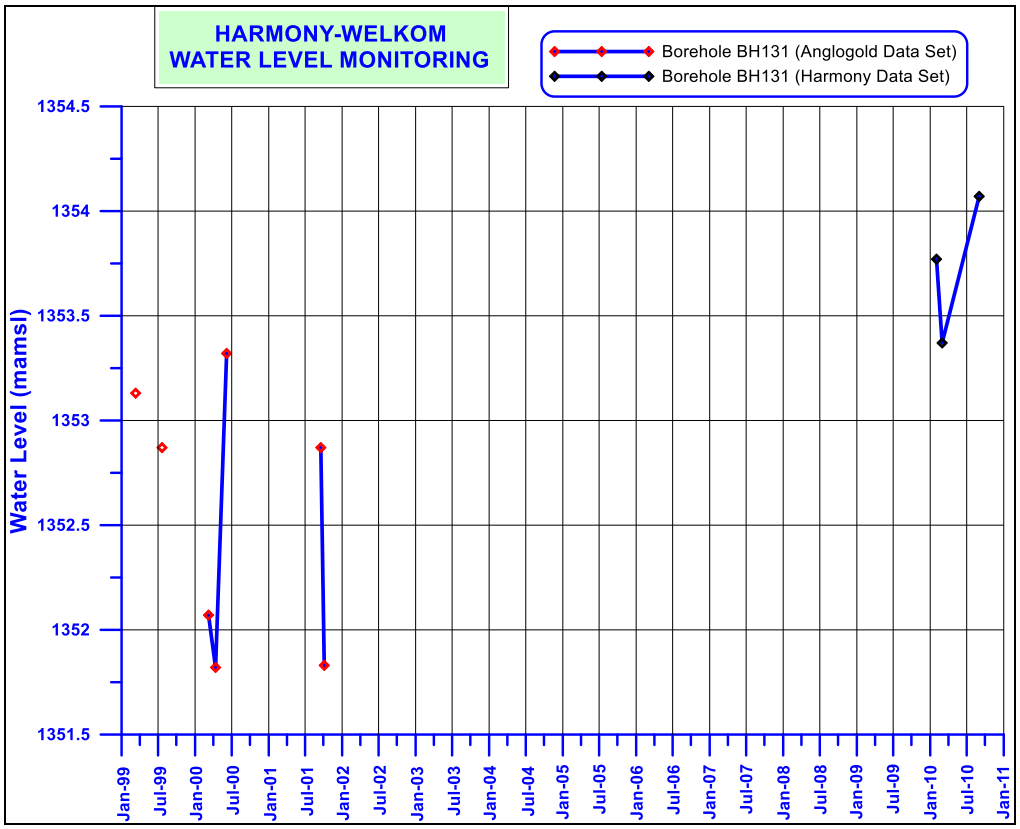

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH125 (Anglogold Data Set)
Borehole BH125 (Harmony Data Set)
Water Level (mamsl)
1304
1302
1300
1298
1296
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

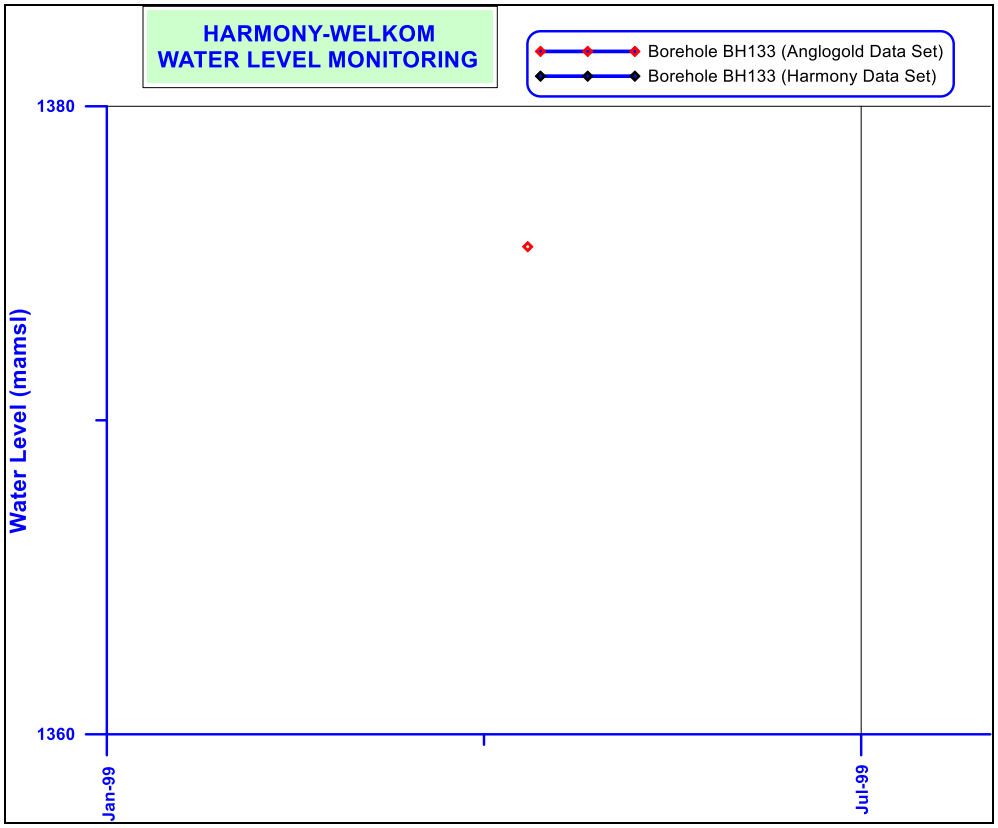

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH126 (Anglogold Data Set)
Borehole BH126 (Harmony Data Set)
Water Level (mamsl)
1299.6
1299.2
1298.8
1298.4
1298
1297.6
1297.2
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

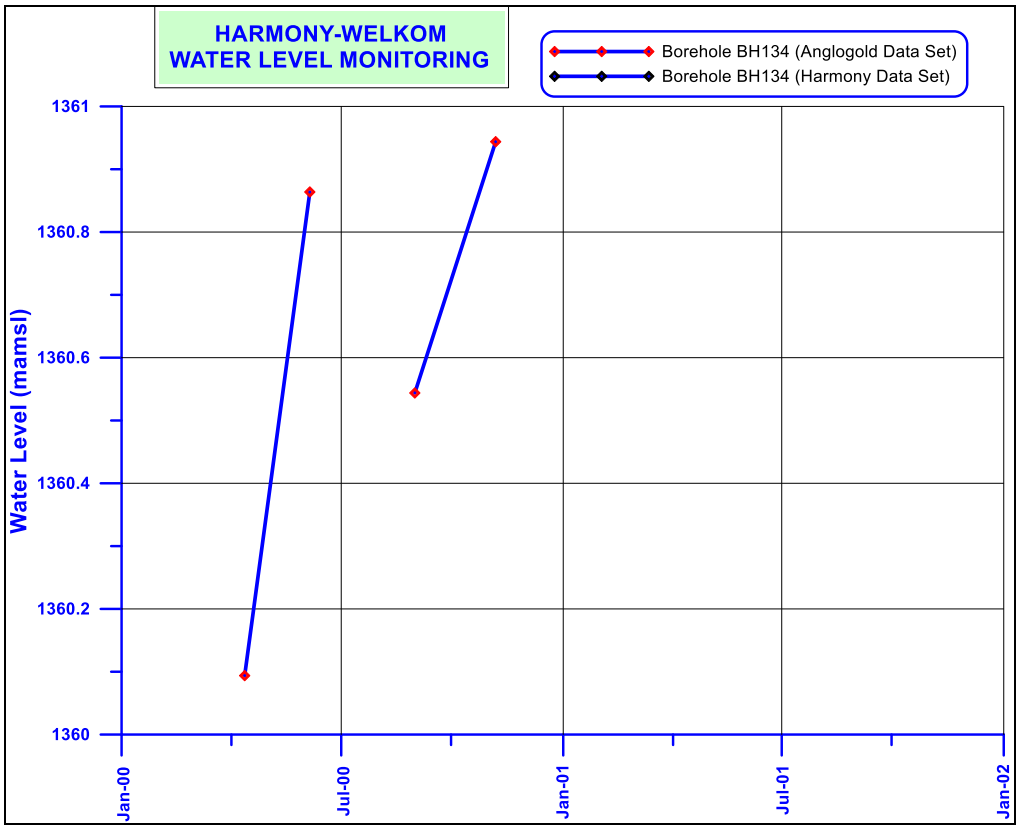

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH128 (Anglogold Data Set)
Borehole BH128 (Harmony Data Set)
Water Level (mamsl)
1294.5
1294
1293.5
1293
1292.5
1292
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

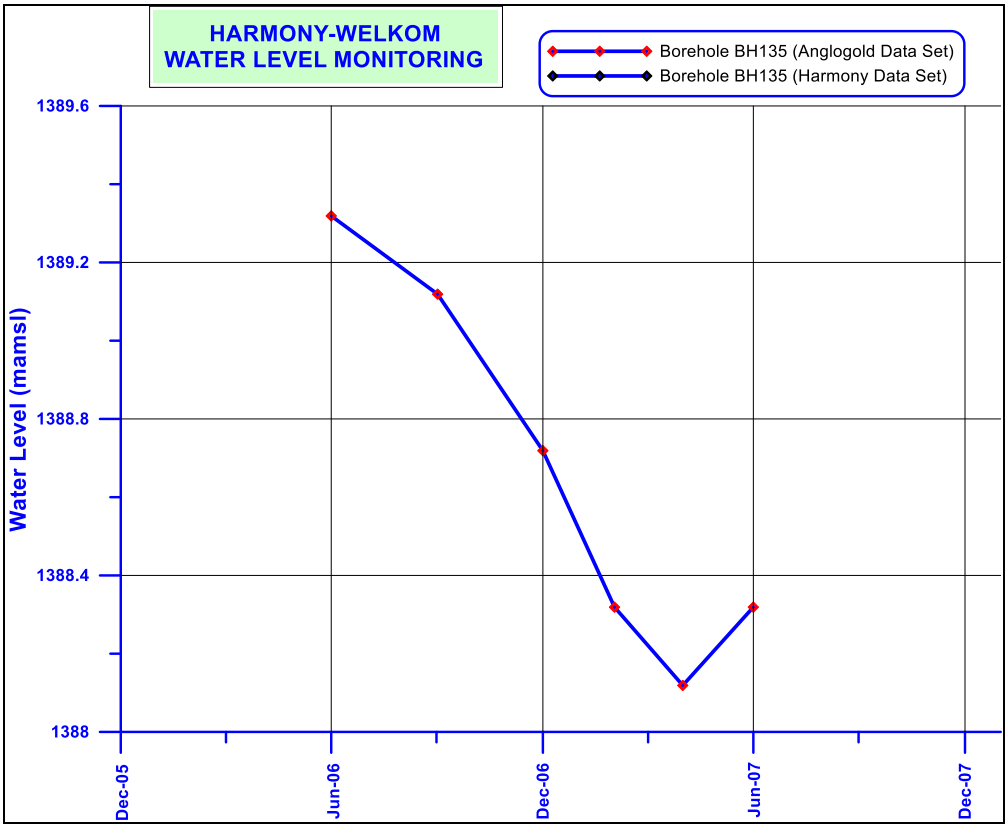

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH129 (Anglogold Data Set)
Borehole BH129 (Harmony Data Set)
Water Level (mamsl)
1376
1375
1374
1373
1372
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04

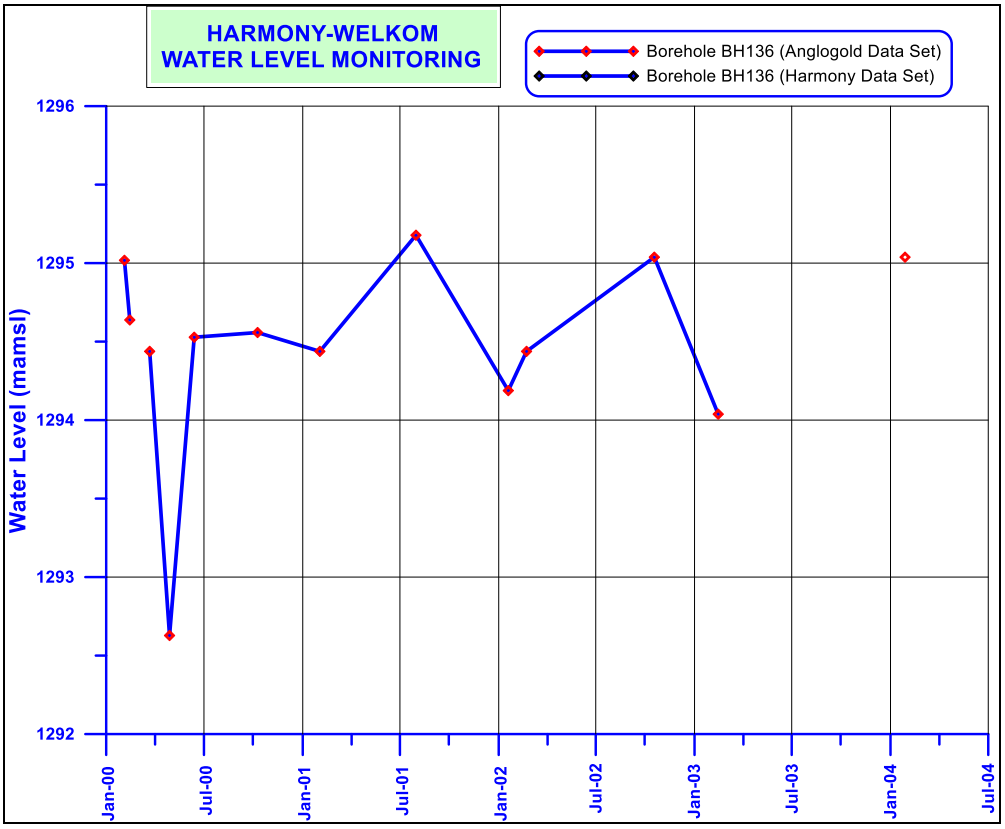

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH13 (Anglogold Data Set)
Borehole BH13 (Harmony Data Set)
Water Level (mamsl)
1344
1343.6
1343.2
1342.8
1342.4
1342
1341.6
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

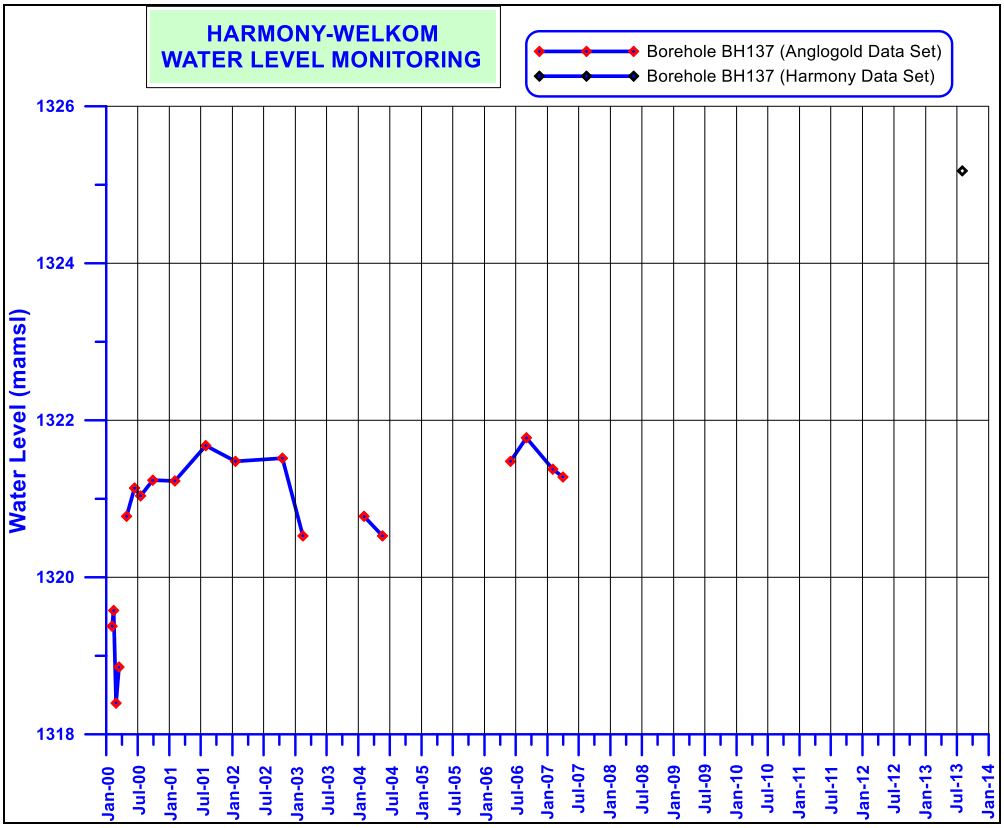

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH131 (Anglogold Data Set)
Borehole BH131 (Harmony Data Set)
Water Level (mamsl)
1354.5
1354
1353.5
1353
1352.5
1352
1351.5
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11

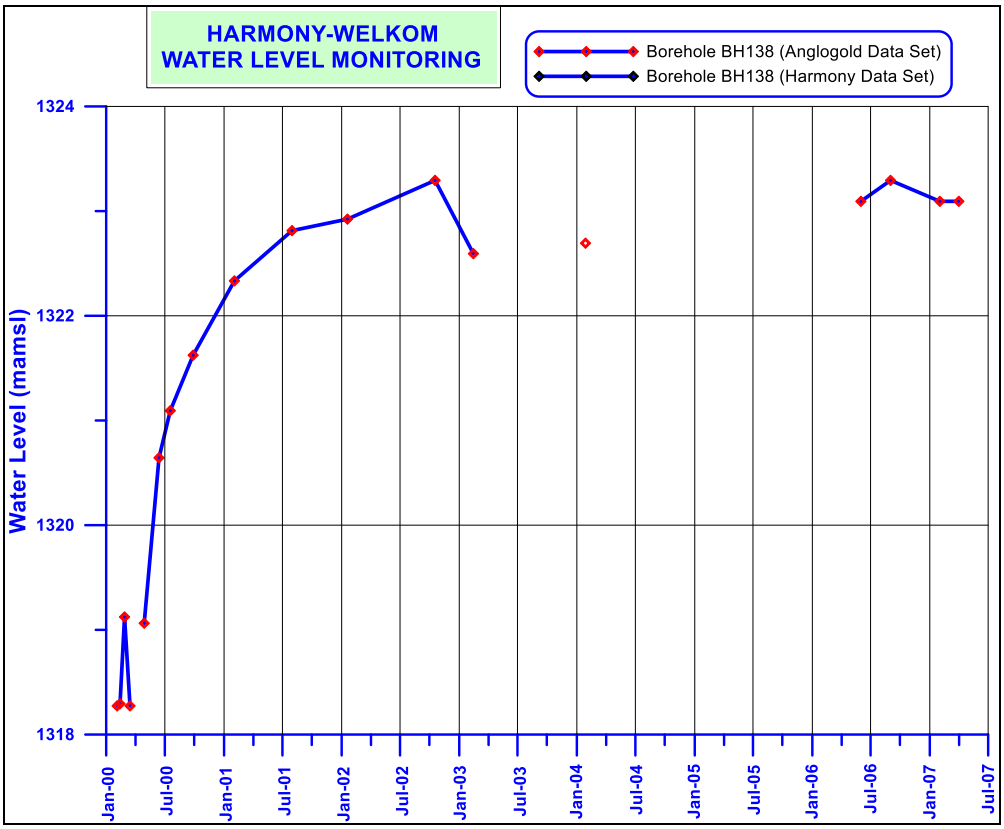

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH133 (Anglogold Data Set)
Borehole BH133 (Harmony Data Set)
Water Level (mamsl)
1380
1360
Jan-99
Jul-99

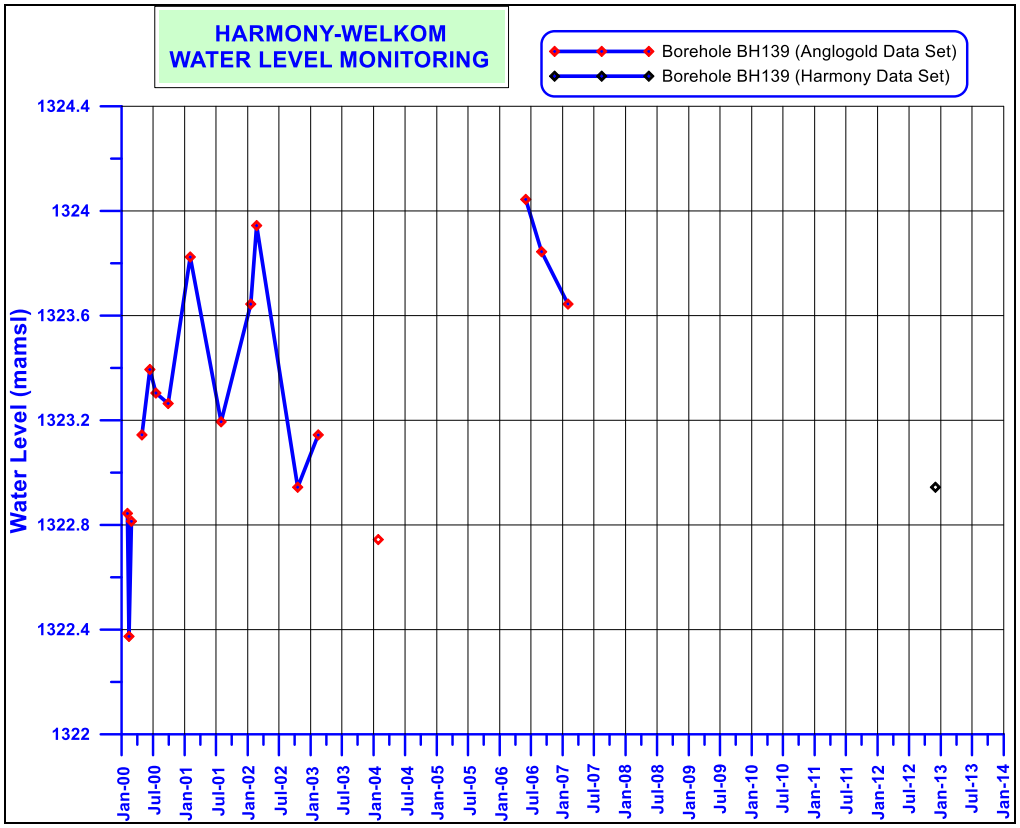

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH134 (Anglogold Data Set)
Borehole BH134 (Harmony Data Set)
Water Level (mamsl)
1361
1360.8
1360.6
1360.4
1360.2
1360
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02

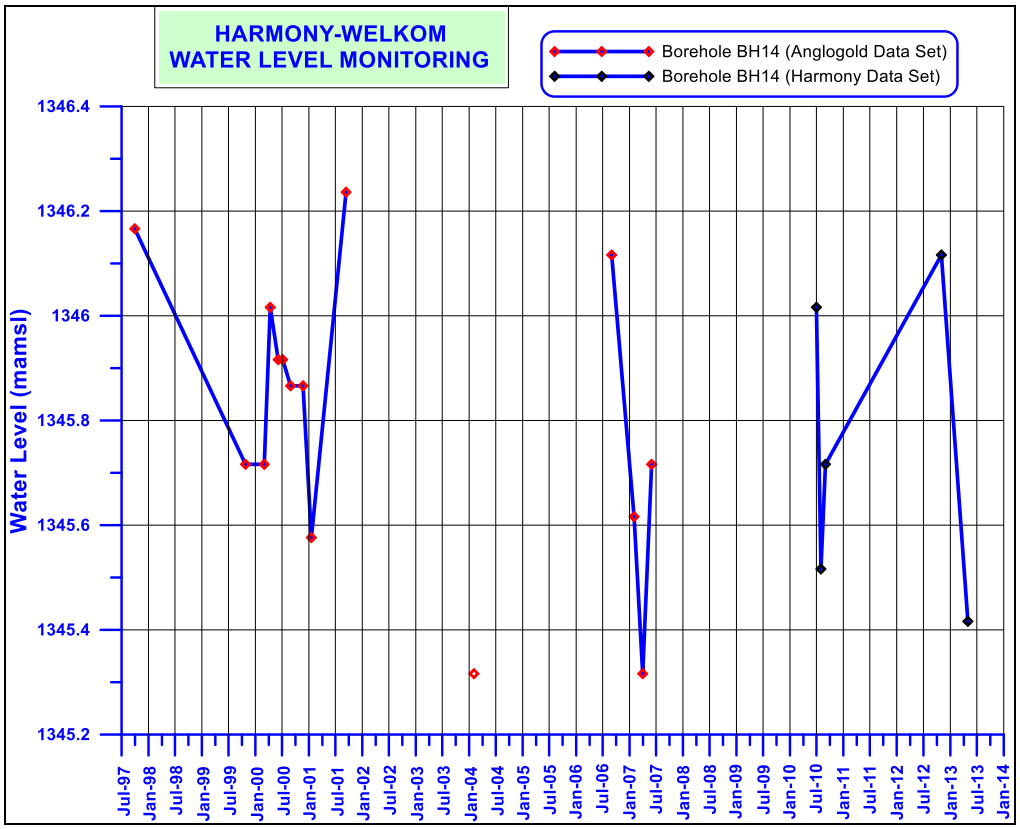

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH135 (Anglogold Data Set)
Borehole BH135 (Harmony Data Set)
Water Level (mamsl)
1389.6
1389.2
1388.8
1388.4
1388
Dec-05
Jun-06
Dec-06
Jun-07
Dec-07

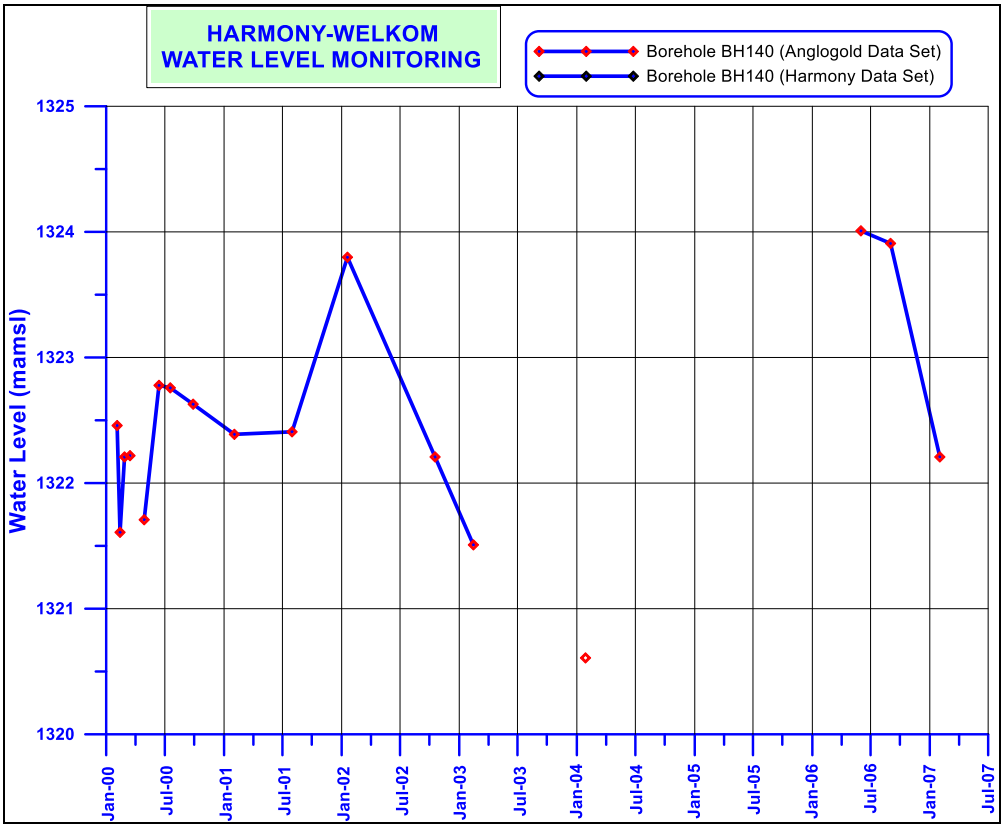

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH136 (Anglogold Data Set)
Borehole BH136 (Harmony Data Set)
Water Level (mamsl)
1296
1295
1294
1293
1292
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04

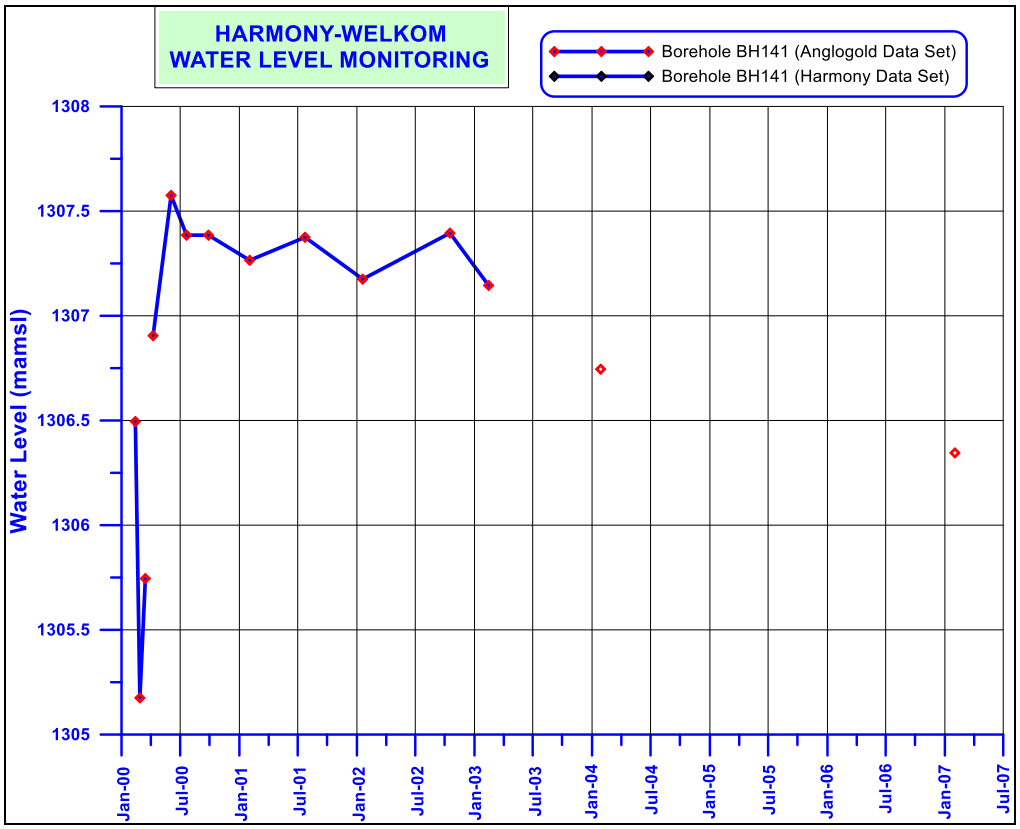

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH137 (Anglogold Data Set)
Borehole BH137 (Harmony Data Set)
Water Level (mamsl)
1326
1324
1322
1320
1318
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

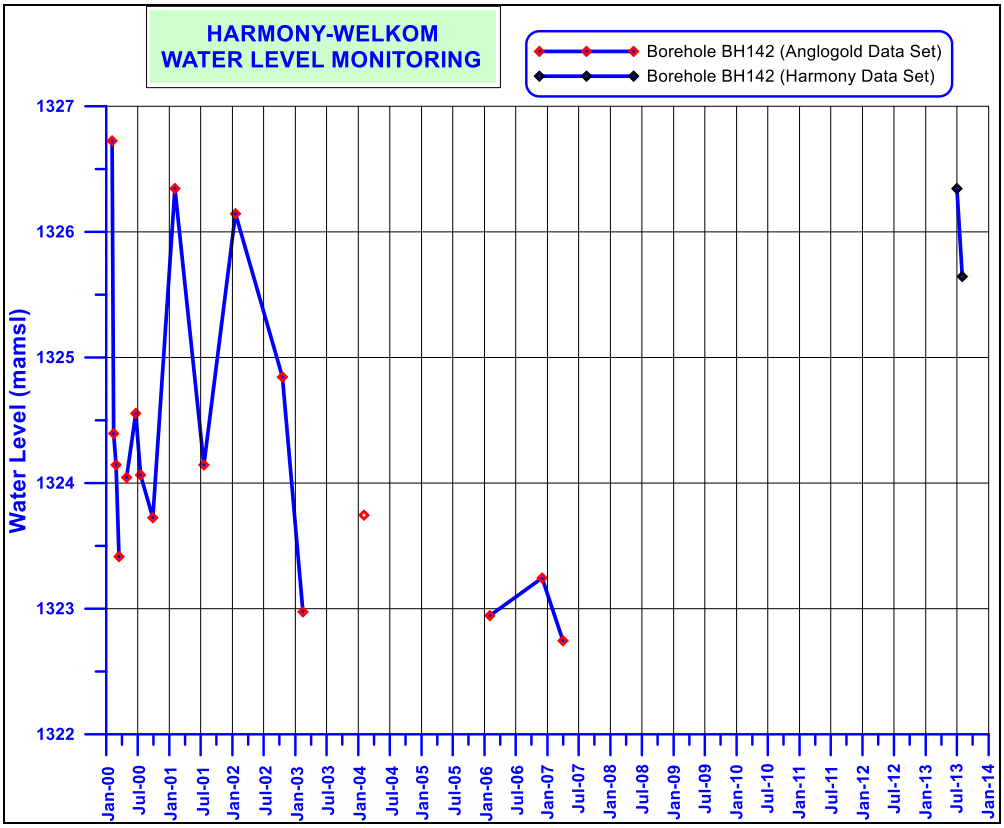

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH138 (Anglogold Data Set)
Borehole BH138 (Harmony Data Set)
Water Level (mamsl)
1324
1322
1320
1318
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

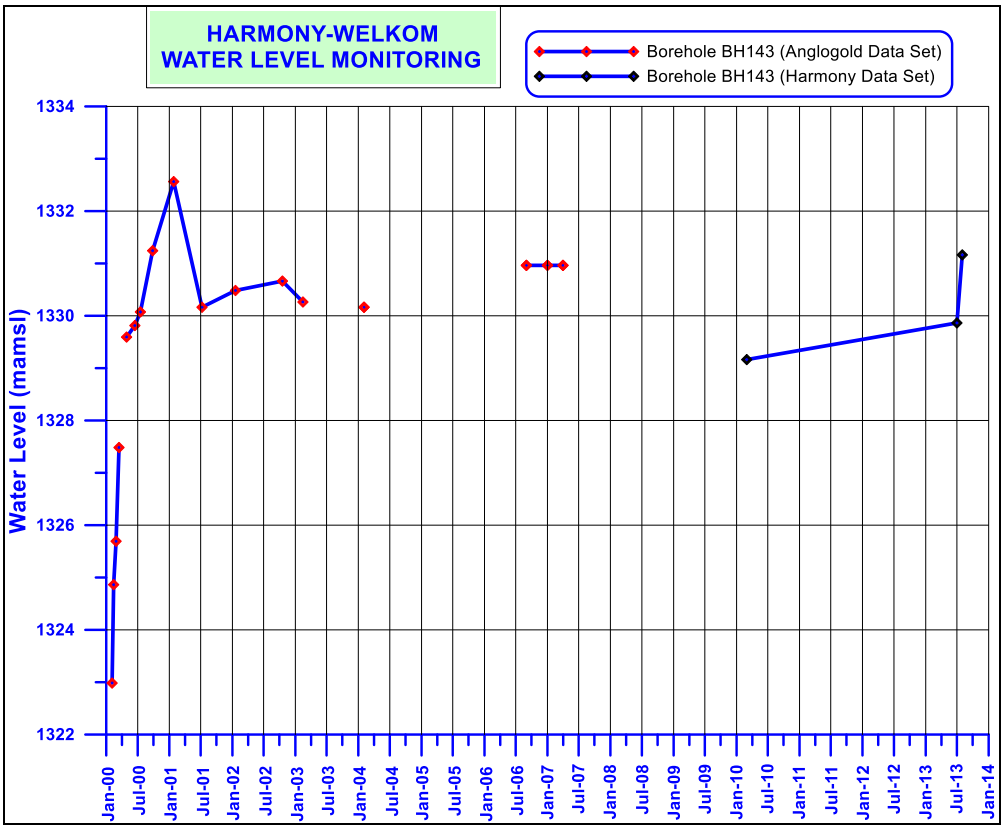

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH139 (Anglogold Data Set)
Borehole BH139 (Harmony Data Set)
Water Level (mamsl)
1324.4
1324
1323.6
1323.2
1322.8
1322.4
1322
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

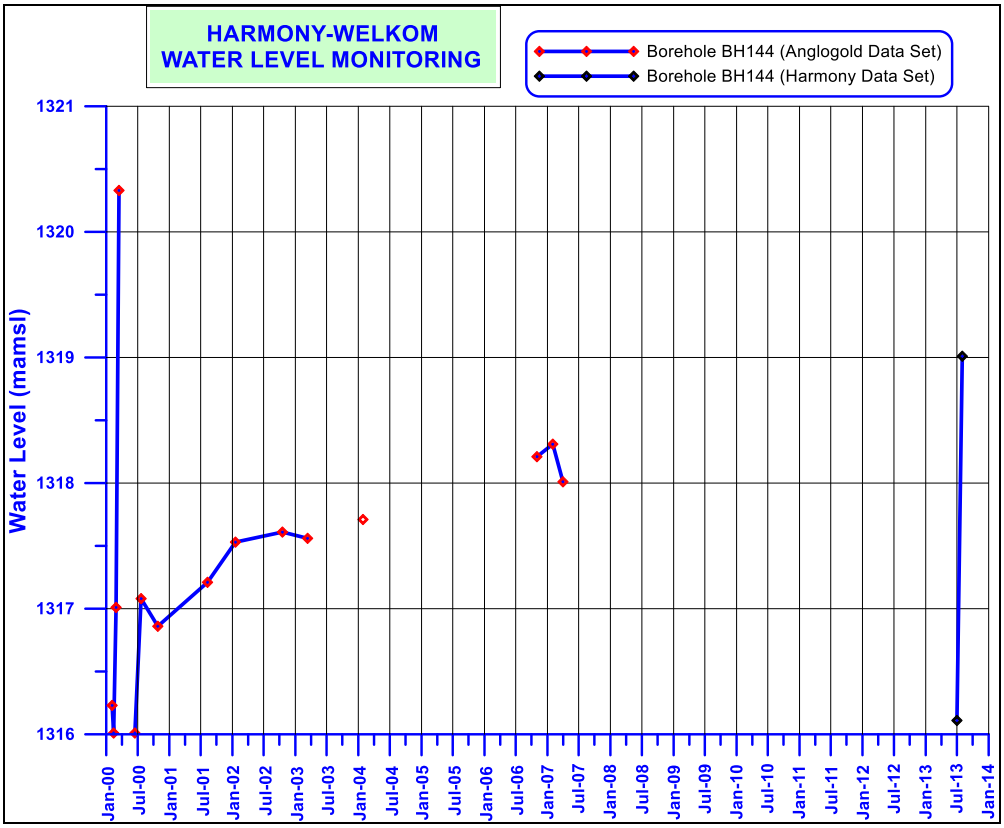

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH14 (Anglogold Data Set)
Borehole BH14 (Harmony Data Set)
Water Level (mamsl)
1346.4
1346.2
1346
1345.8
1345.6
1345.4
1345.2
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

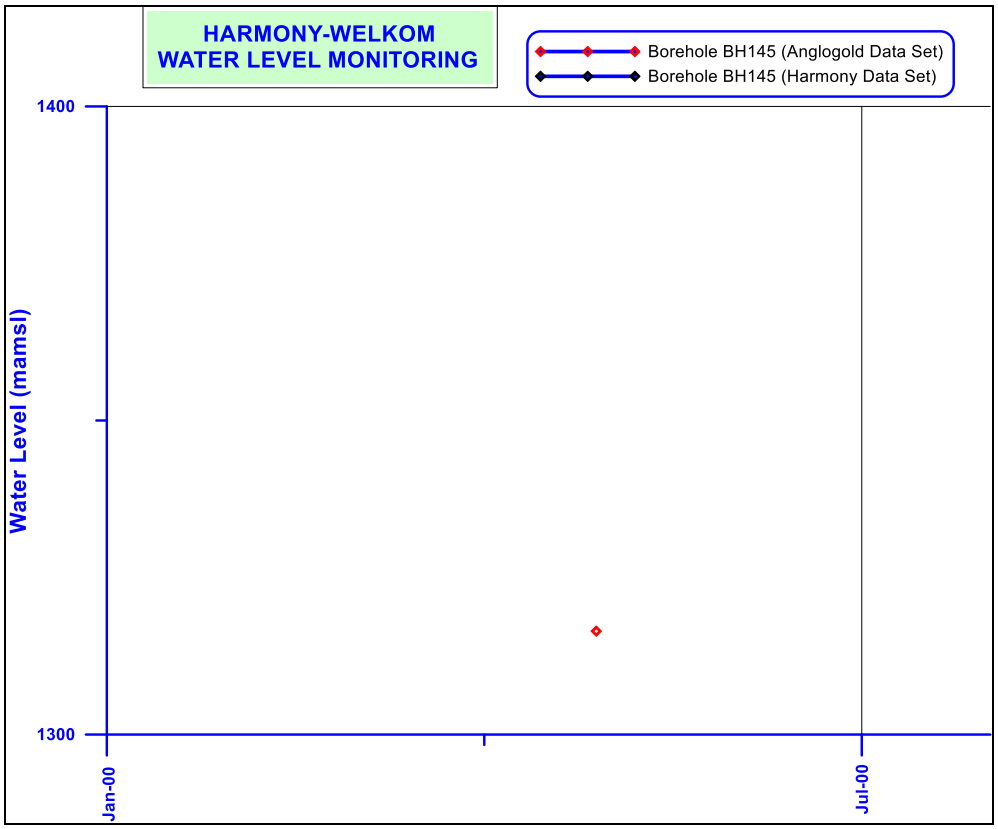

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH140 (Anglogold Data Set)
Borehole BH140 (Harmony Data Set)
Water Level (mamsl)
1325
1324
1323
1322
1321
1320
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

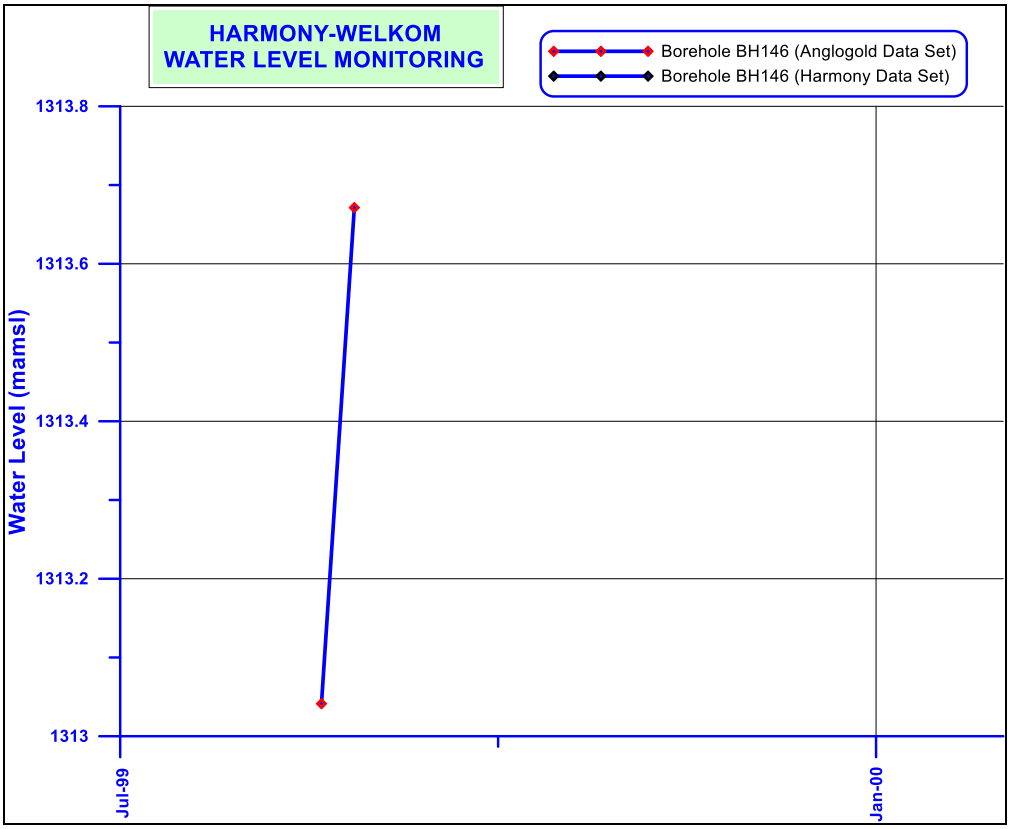

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH141 (Anglogold Data Set)
Borehole BH141 (Harmony Data Set)
Water Level (mamsl)
1308
1307.5
1307
1306.5
1306
1305.5
1305
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

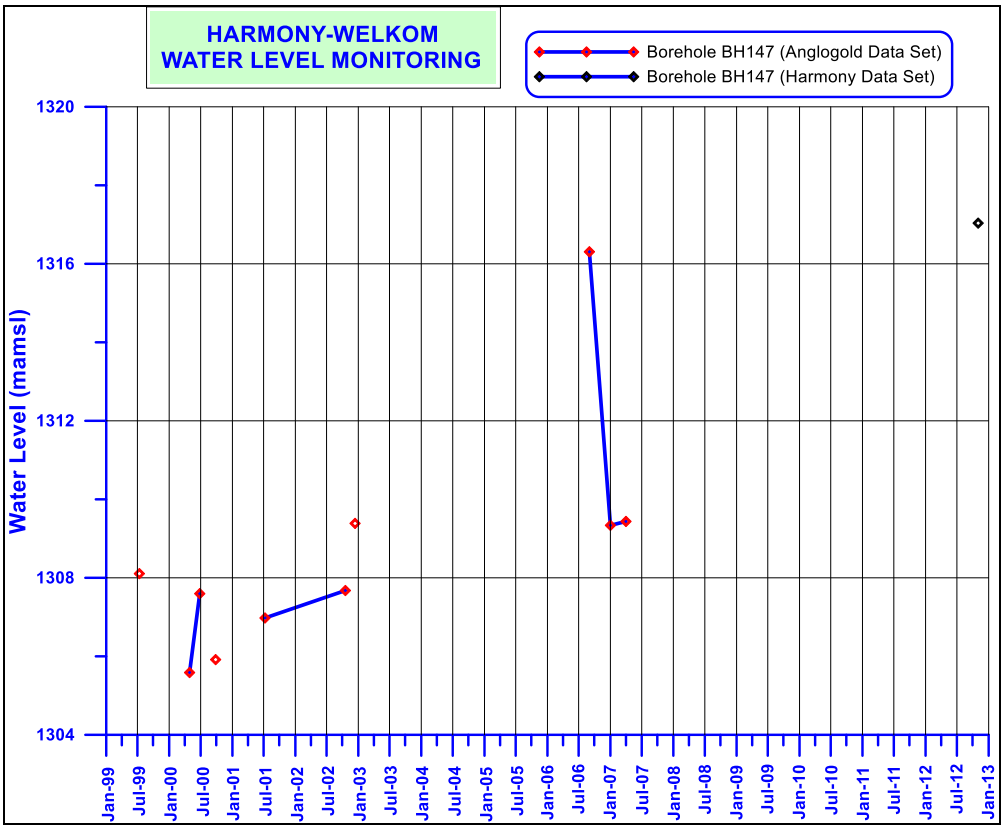

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH142 (Anglogold Data Set)
Borehole BH142 (Harmony Data Set)
Water Level (mamsl)
1327
1326
1325
1324
1323
1322
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

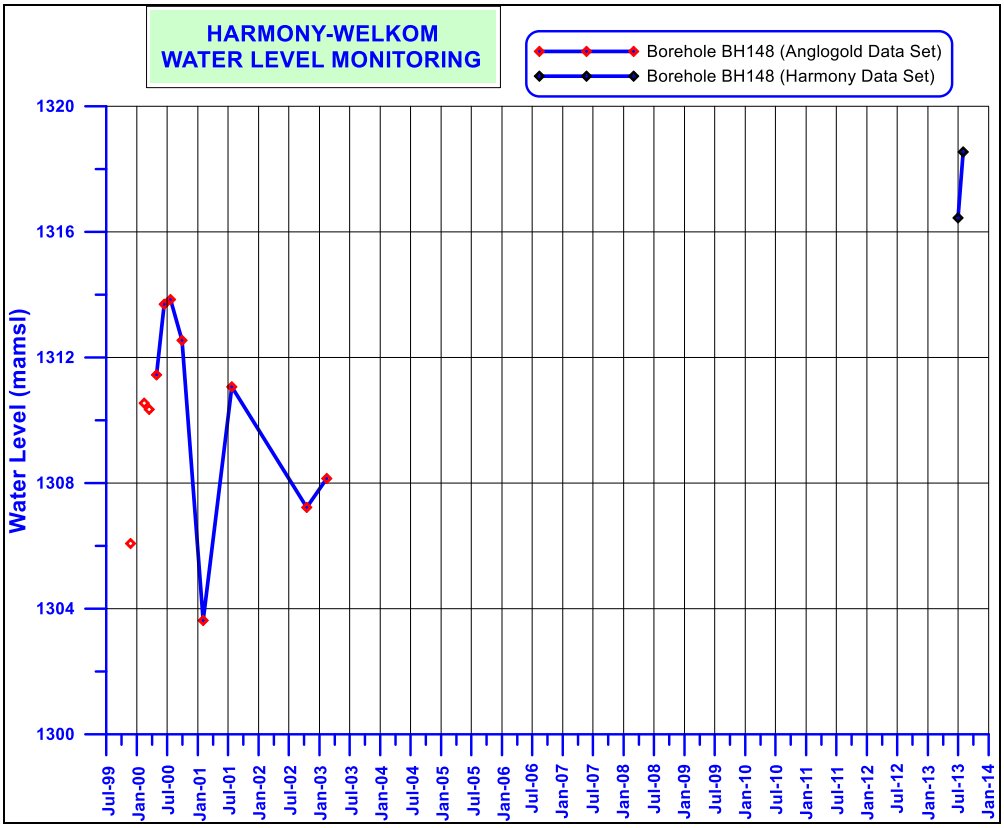

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH143 (Anglogold Data Set)
Borehole BH143 (Harmony Data Set)
Water Level (mamsl)
1334
1332
1330
1328
1326
1324
1322
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

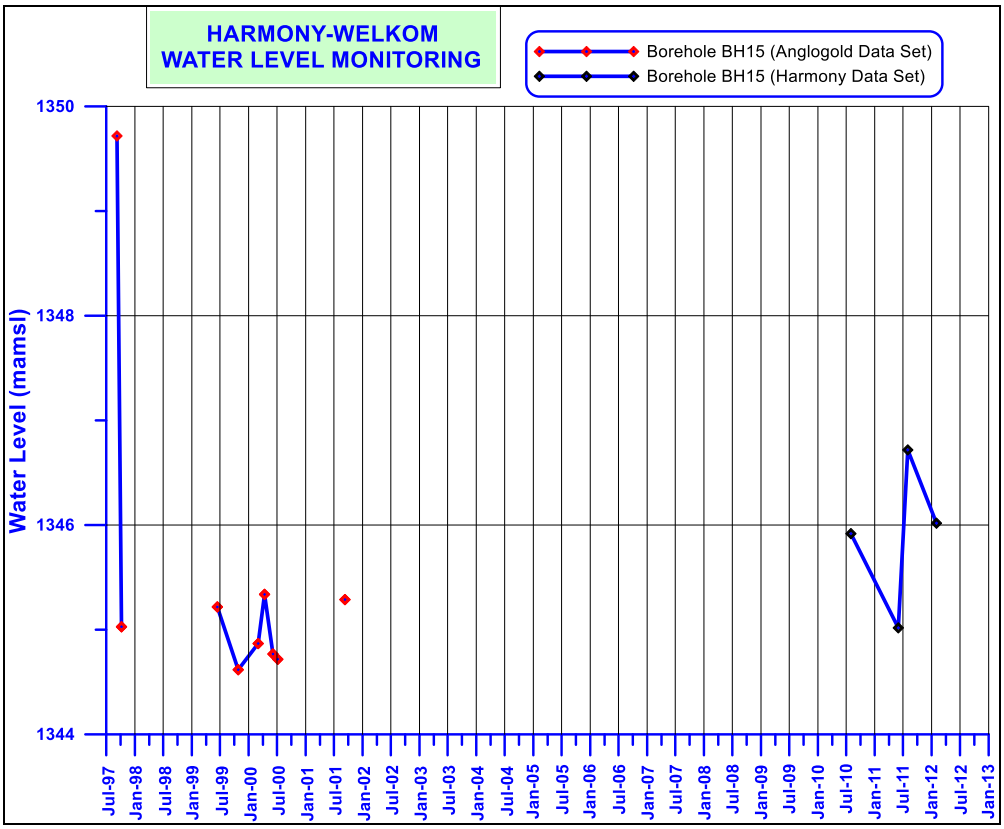

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH144 (Anglogold Data Set)
Borehole BH144 (Harmony Data Set)
Water Level (mamsl)
1321
1320
1319
1318
1317
1316
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

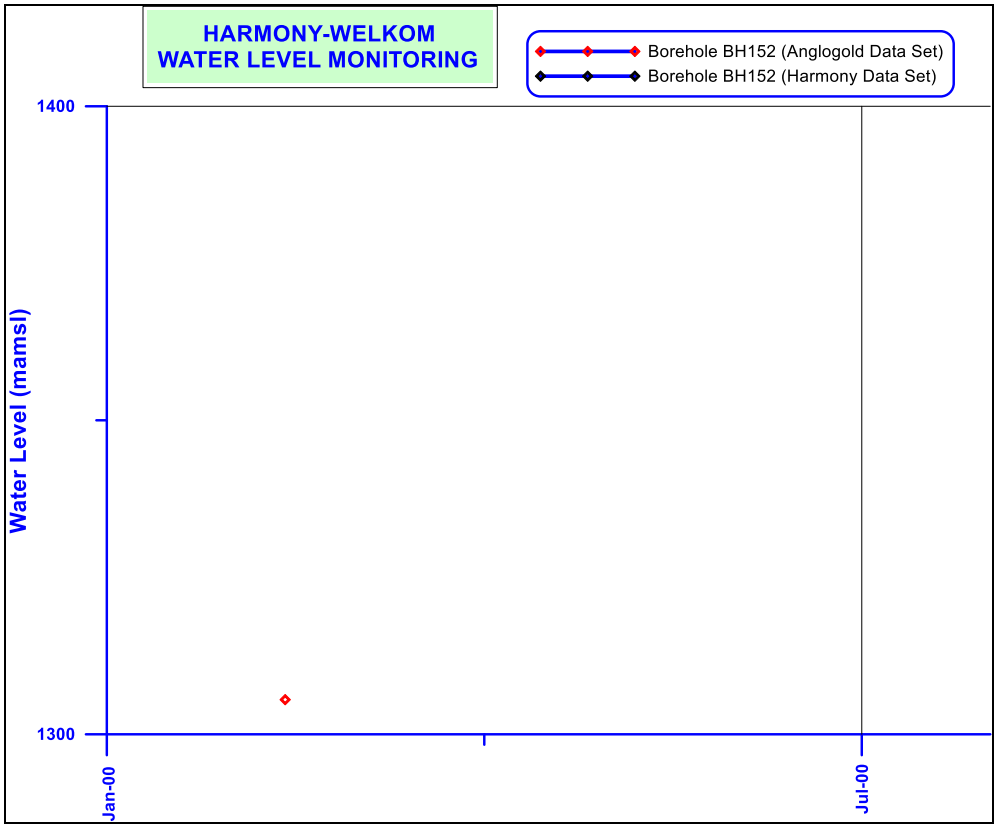

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH145 (Anglogold Data Set)
Borehole BH145 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jan-00
Jul-00

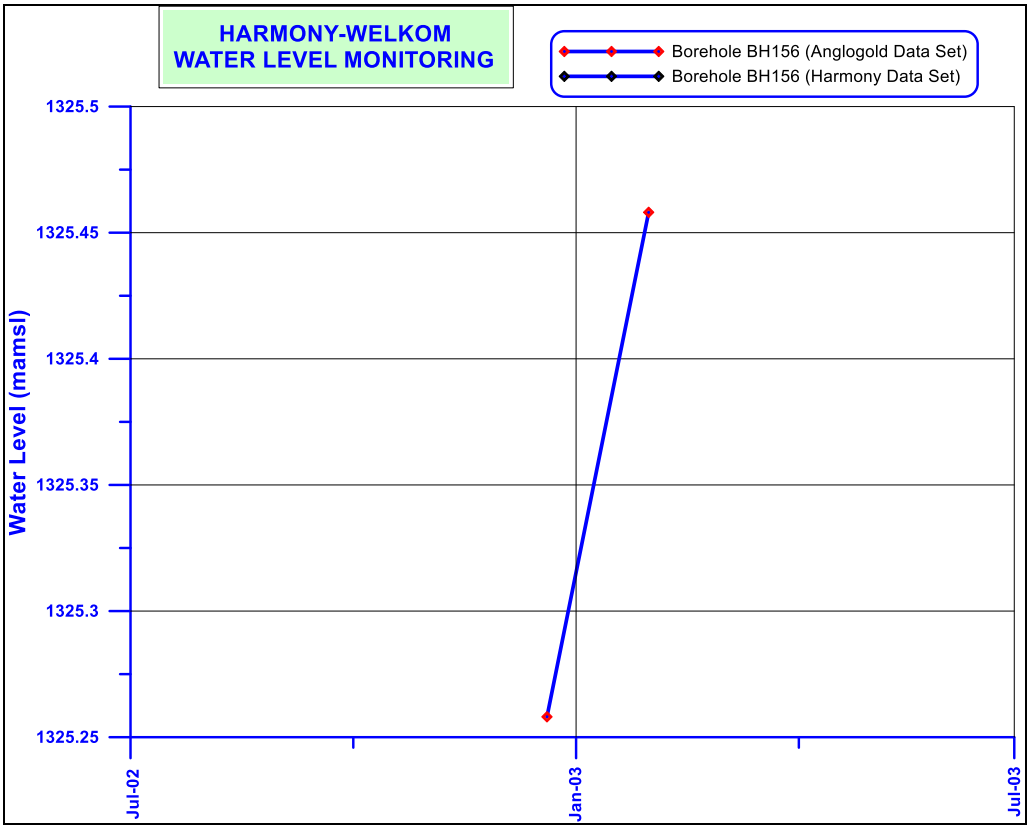

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH146 (Anglogold Data Set)
Borehole BH146 (Harmony Data Set)
Water Level (mamsl)
1313.8
1313.6
1313.4
1313.2
1313
Jul-99
Jan-00

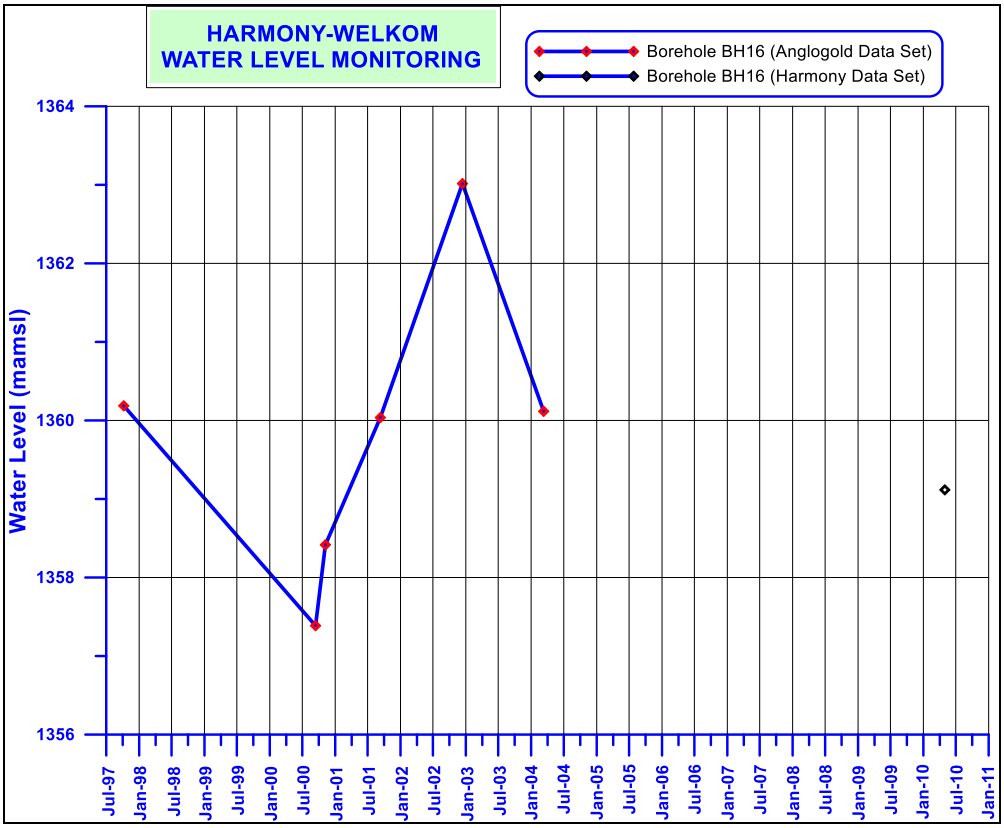

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH147 (Anglogold Data Set)
Borehole BH147 (Harmony Data Set)
Water Level (mamsl)
1320
1316
1312
1308
1304
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13

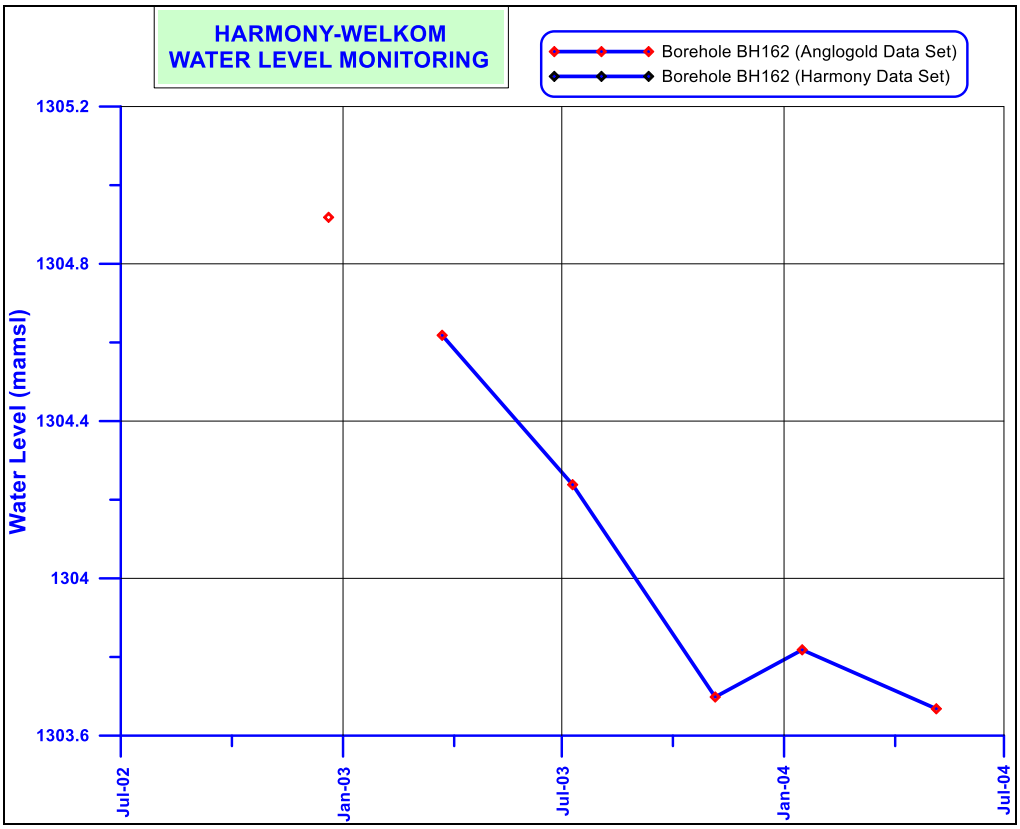

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH148 (Anglogold Data Set)
Borehole BH148 (Harmony Data Set)
Water Level (mamsl)
1320
1316
1312
1308
1304
1300
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

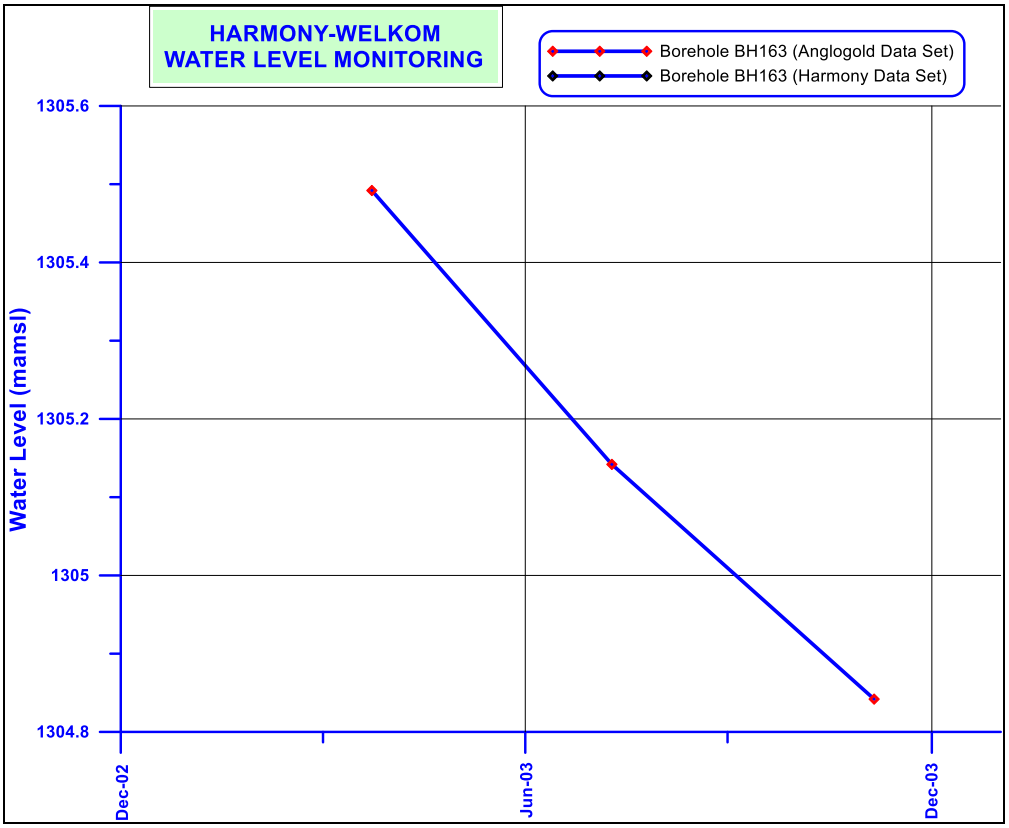

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH15 (Anglogold Data Set)
Borehole BH15 (Harmony Data Set)
Water Level (mamsl)
1350
1348
1346
1344
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13

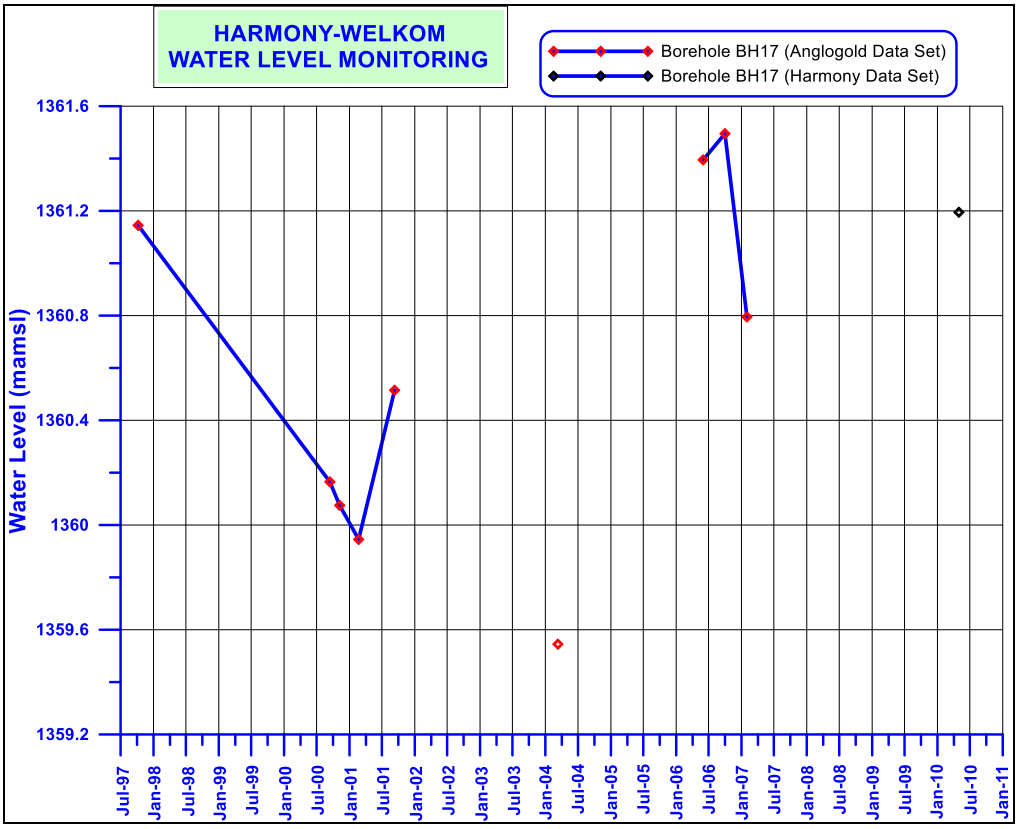

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH152 (Anglogold Data Set)
Borehole BH152 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jan-00
Jul-00

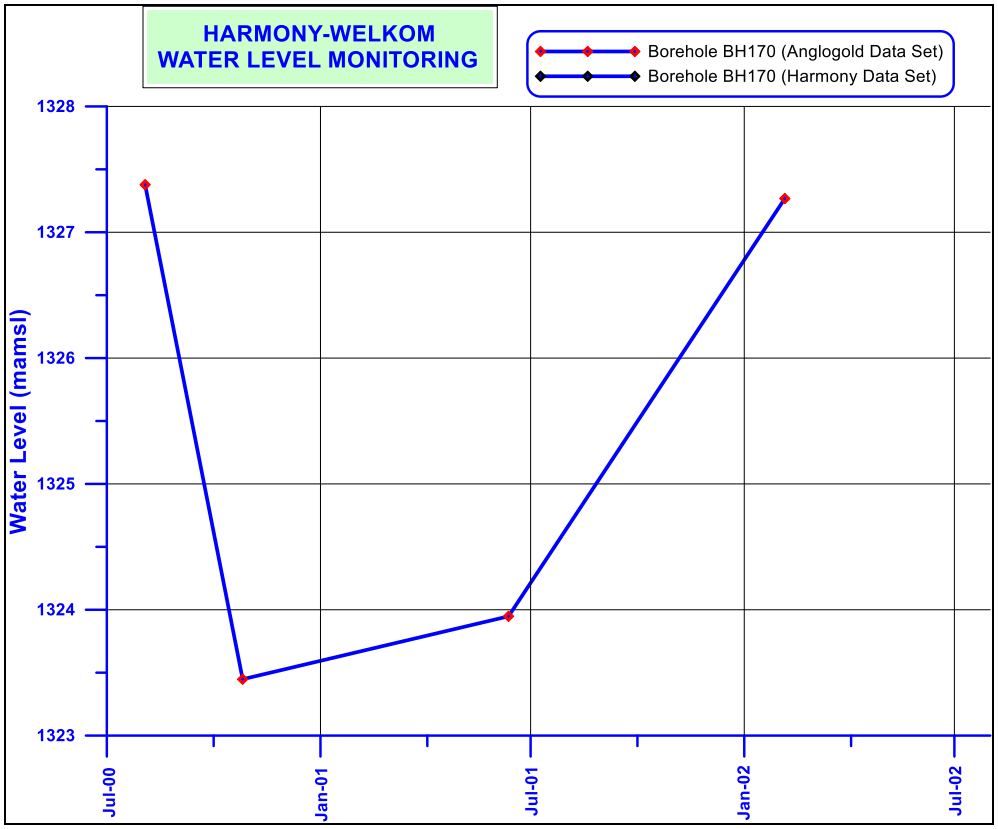

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH156 (Anglogold Data Set)
Borehole BH156 (Harmony Data Set)
Water Level (mamsl)
1325.5
1325.45
1325.4
1325.35
1325.3
1325.25
Jul-02
Jan-03
Jul-03

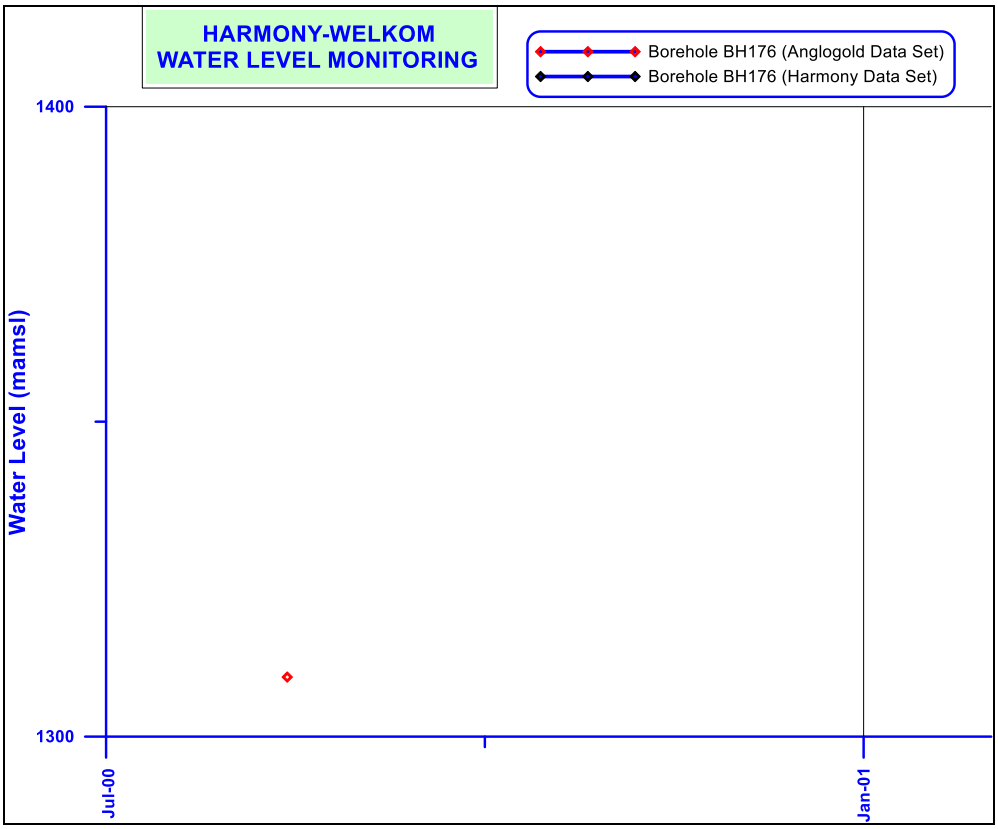

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH16 (Anglogold Data Set)
Borehole BH16 (Harmony Data Set)
Water Level (mamsl)
1364
1362
1360
1358
1356
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11

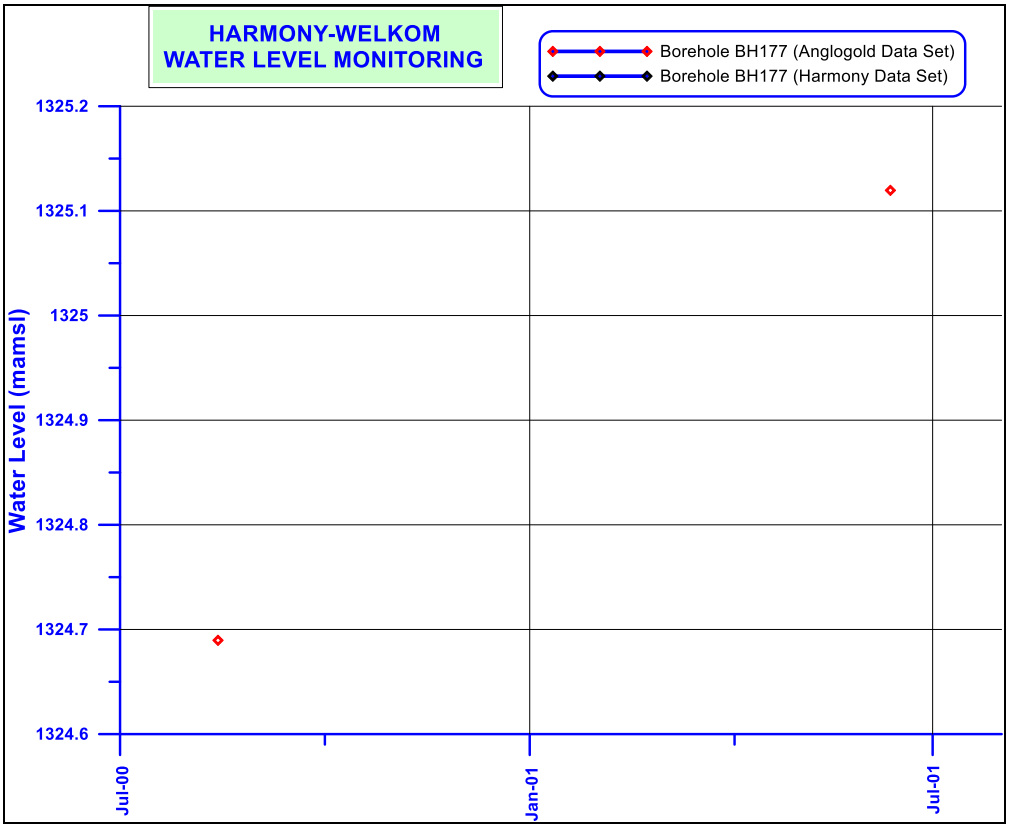

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH162 (Anglogold Data Set)
Borehole BH162 (Harmony Data Set)
Water Level (mamsl)
1305.2
1304.8
1304.4
1304
1303.6
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04

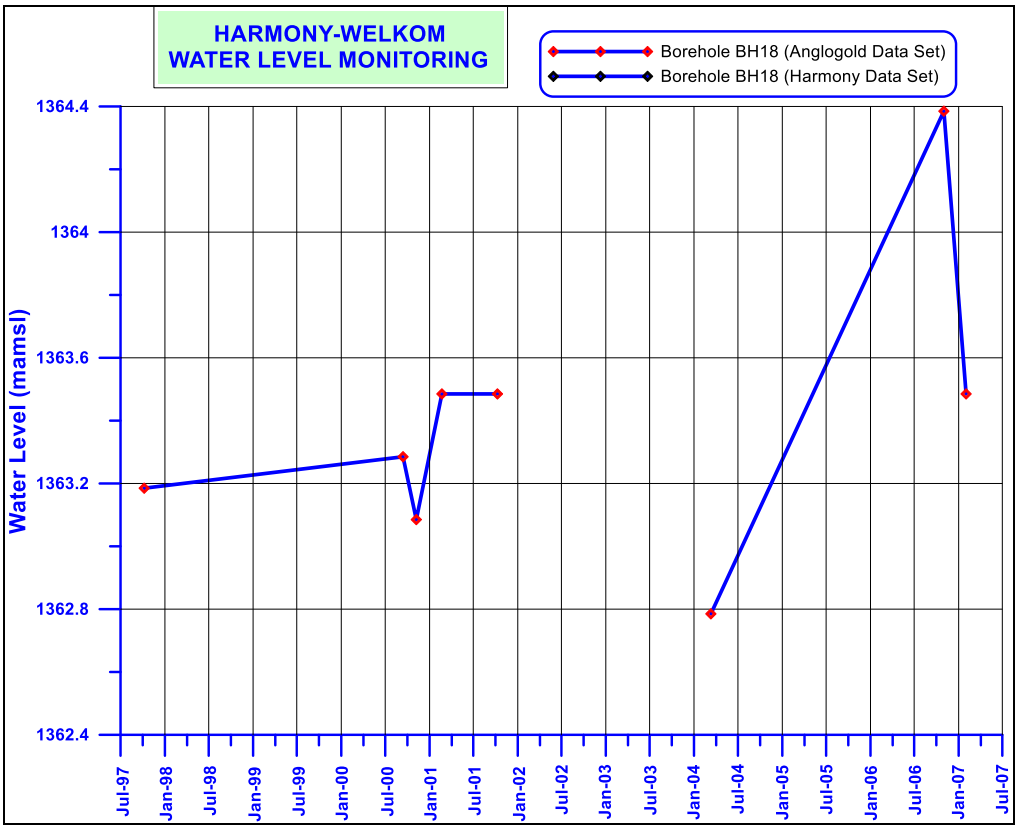

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH163 (Anglogold Data Set)
Borehole BH163 (Harmony Data Set)
Water Level (mamsl)
1305.6
1305.4
1305.2
1305
1304.8
Dec-02
Jun-03
Dec-03

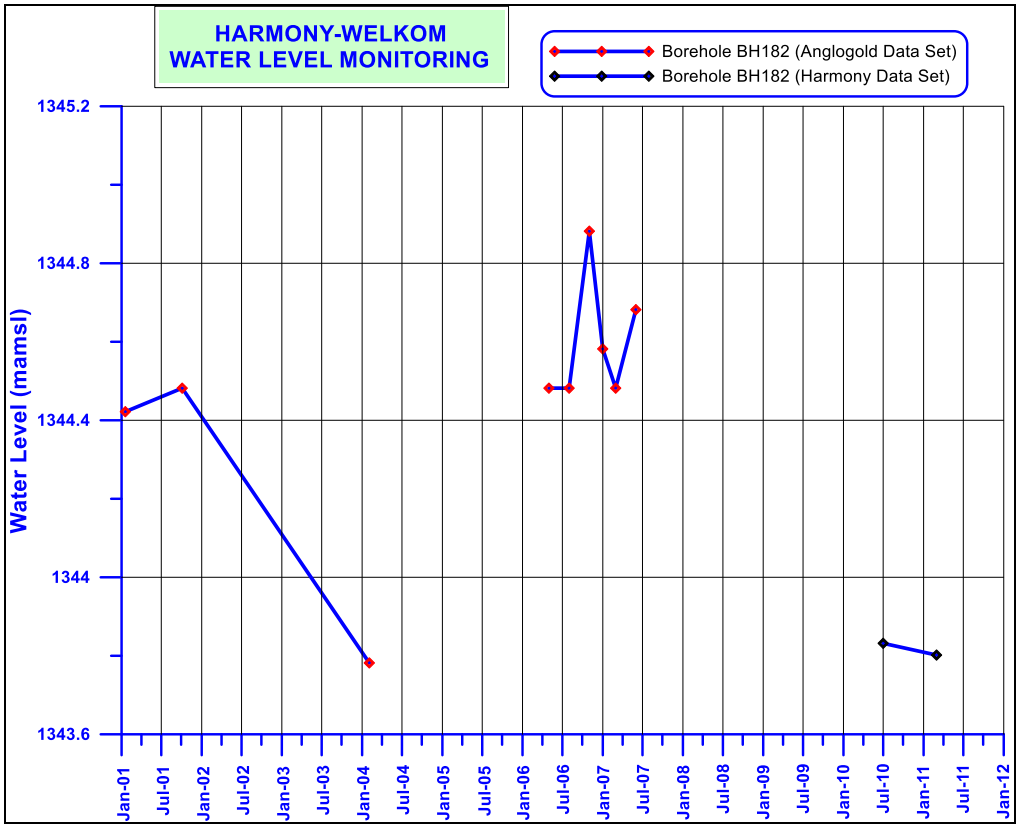

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH17 (Anglogold Data Set)
Borehole BH17 (Harmony Data Set)
Water Level (mamsl)
1361.6
1361.2
1360.8
1360.4
1360
1359.6
1359.2
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11

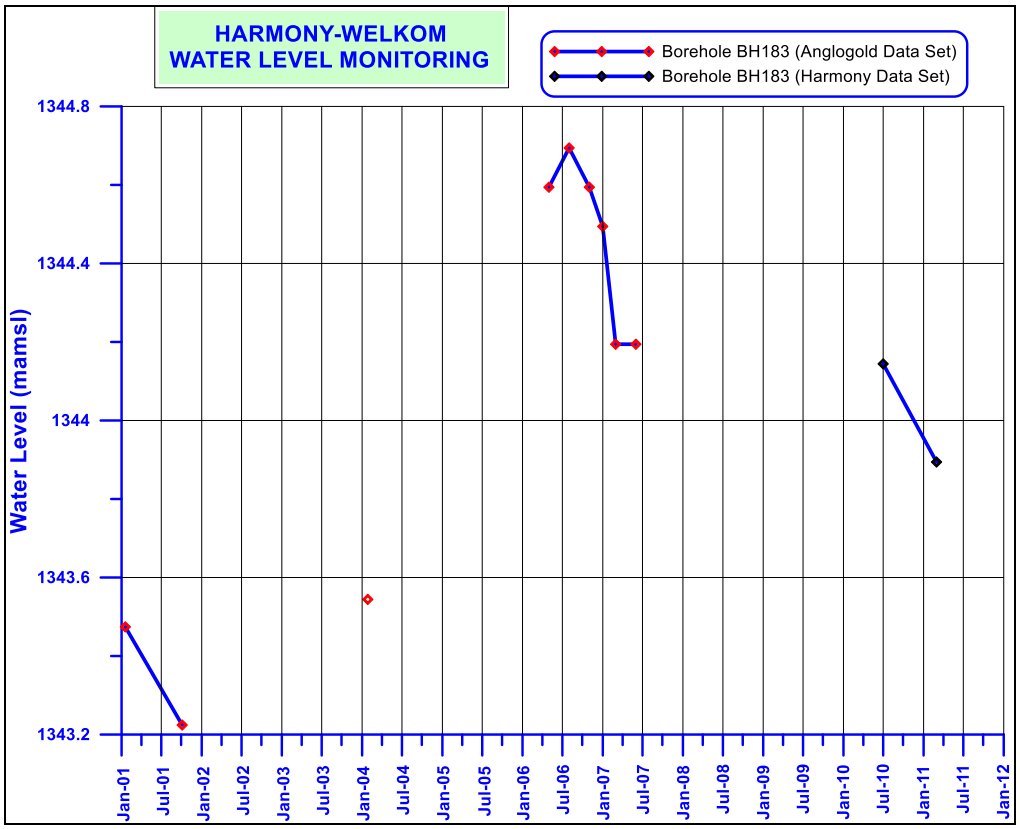

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH170 (Anglogold Data Set)
Borehole BH170 (Harmony Data Set)
Water Level (mamsl)
1328
1327
1326
1325
1324
1323
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02

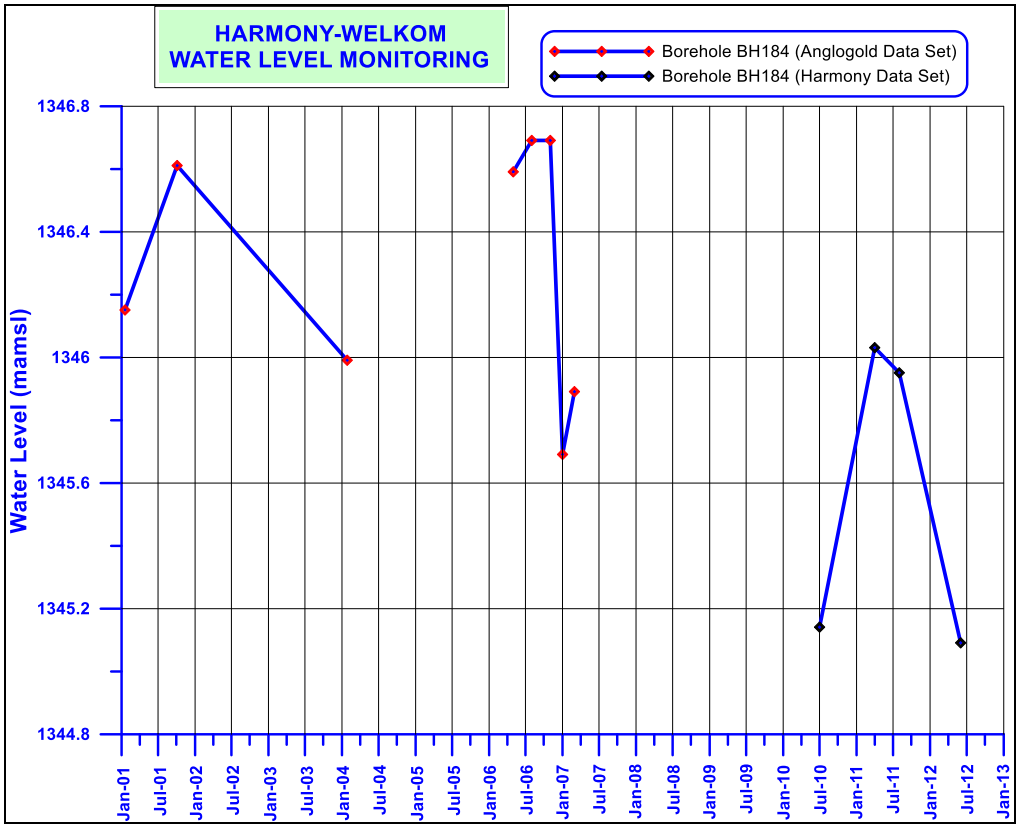

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH176 (Anglogold Data Set)
Borehole BH176 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jul-00
Jan-01

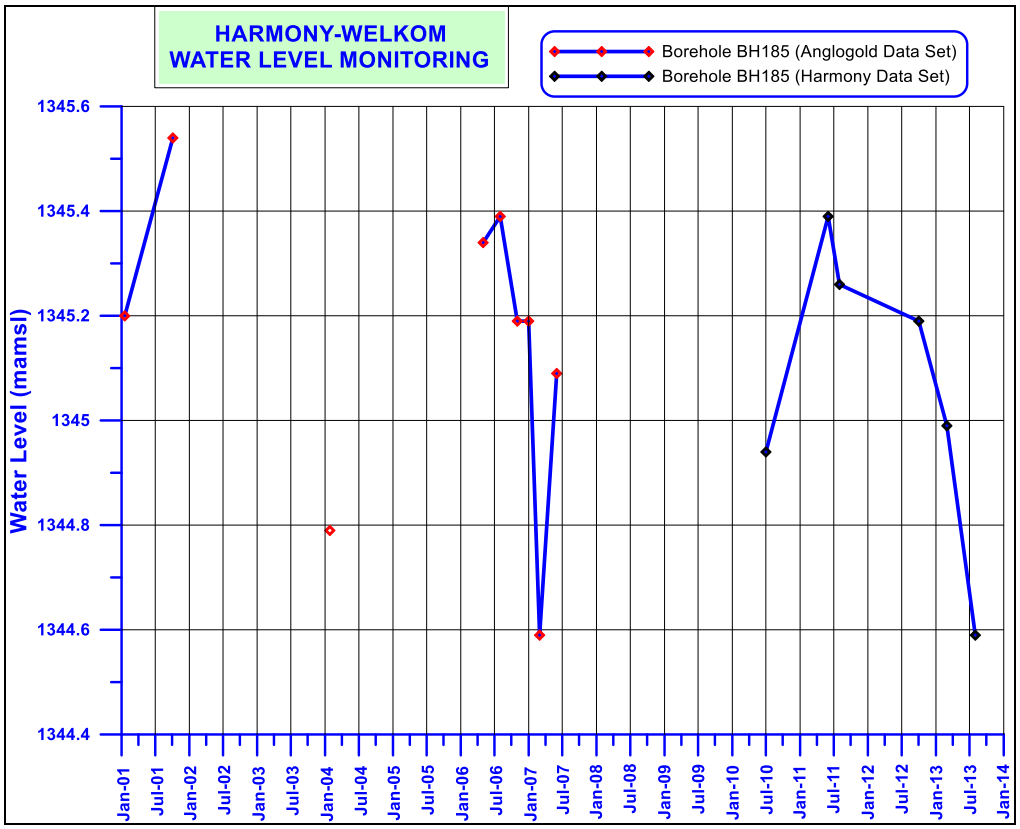

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH177 (Anglogold Data Set)
Borehole BH177 (Harmony Data Set)
Water Level (mamsl)
1325.2
1325.1
1325
1324.9
1324.8
1324.7
1324.6
Jul-00
Jan-01
Jul-01

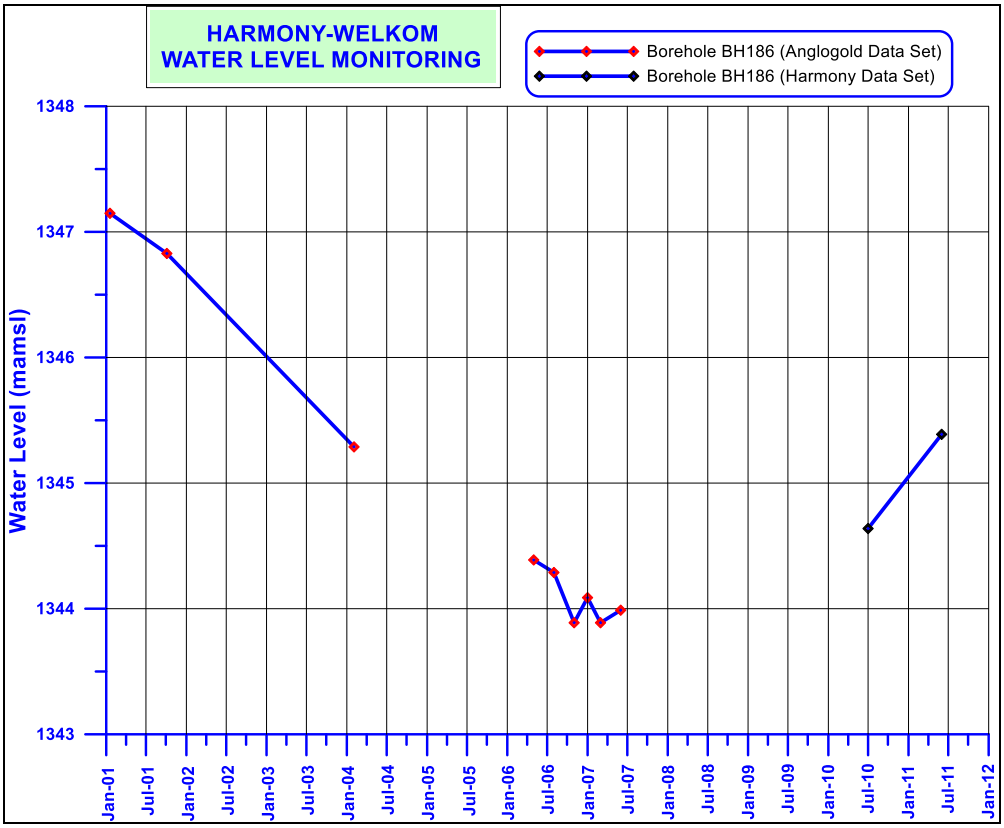

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH18 (Anglogold Data Set)
Borehole BH18 (Harmony Data Set)
Water Level (mamsl)
1364.4
1364
1363.6
1363.2
1362.8
1362.4
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

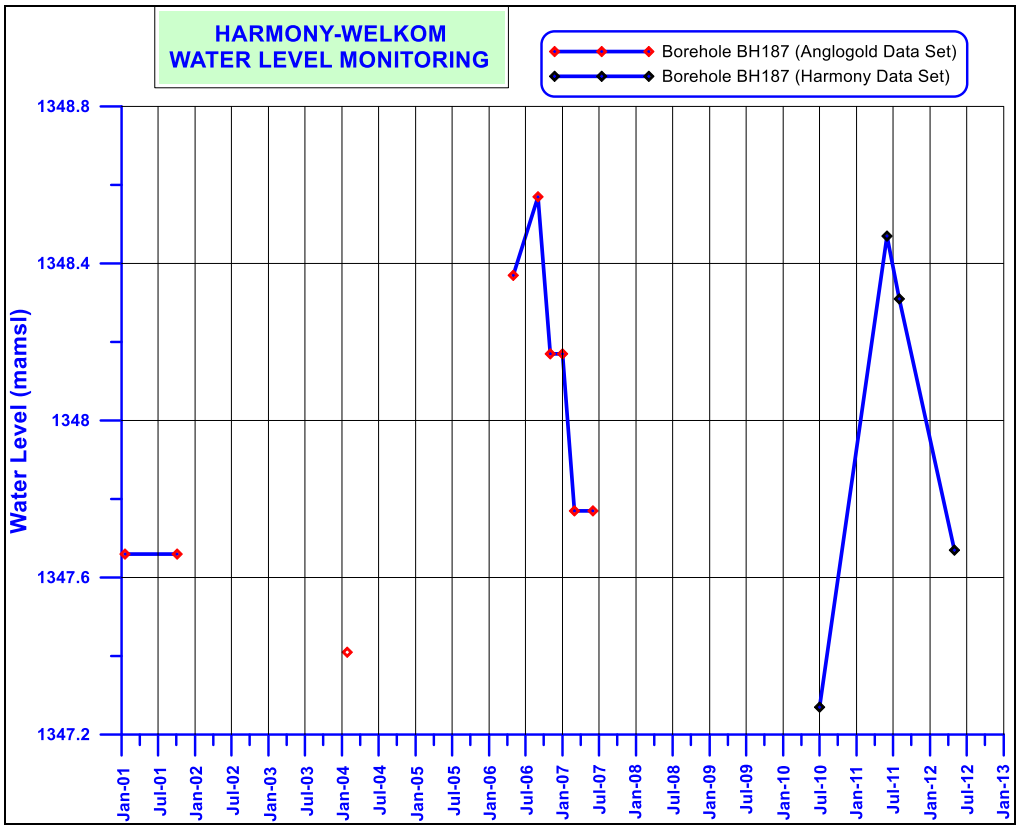

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH182 (Anglogold Data Set)
Borehole BH182 (Harmony Data Set)
Water Level (mamsl)
1345.2
1344.8
1344.4
1344
1343.6
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12

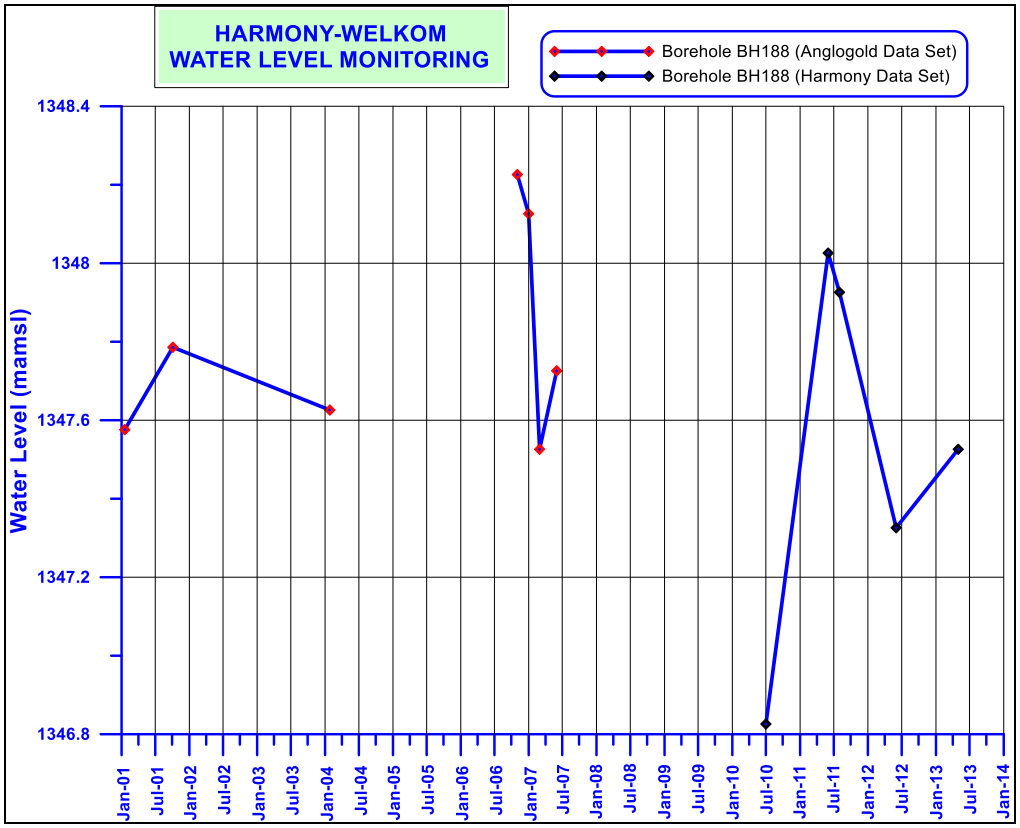

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH183 (Anglogold Data Set)
Borehole BH183 (Harmony Data Set)
Water Level (mamsl)
1344.8
1344.4
1344
1343.6
1343.2
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12

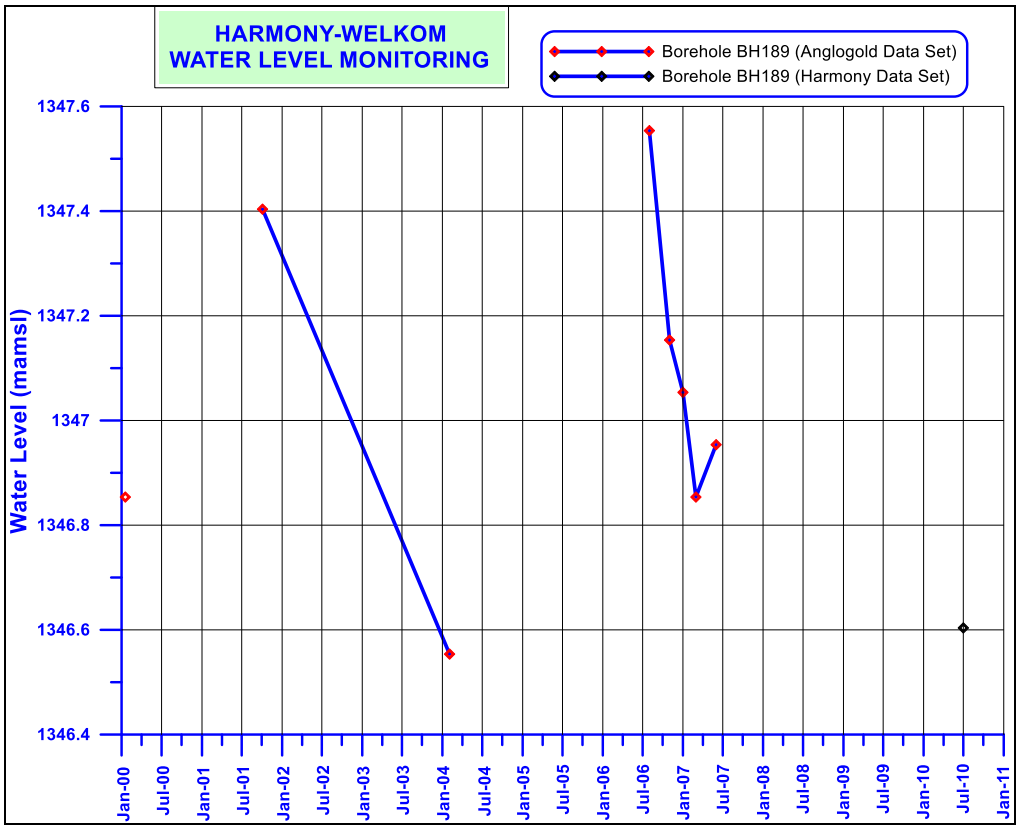

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH184 (Anglogold Data Set)
Borehole BH184 (Harmony Data Set)
Water Level (mamsl)
1346.8
1346.4
1346
1345.6
1345.2
1344.8
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13

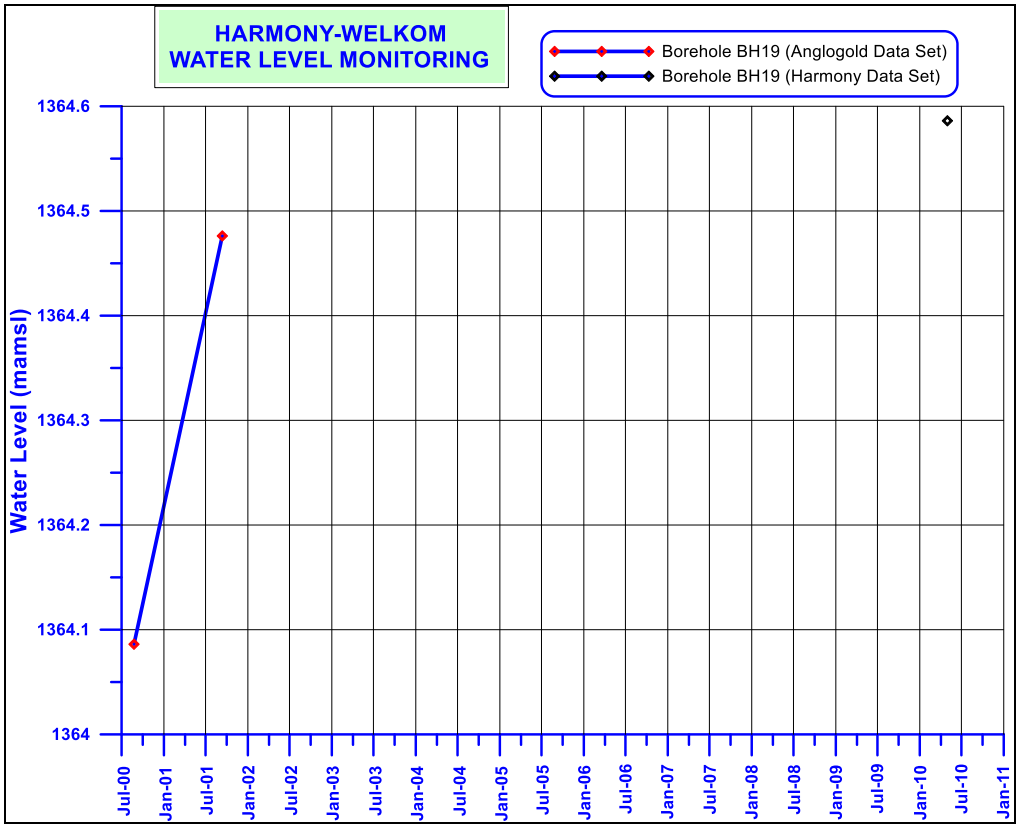

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH185 (Anglogold Data Set)
Borehole BH185 (Harmony Data Set)
Water Level (mamsl)
1345.6
1345.4
1345.2
1345
1344.8
1344.6
1344.4
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

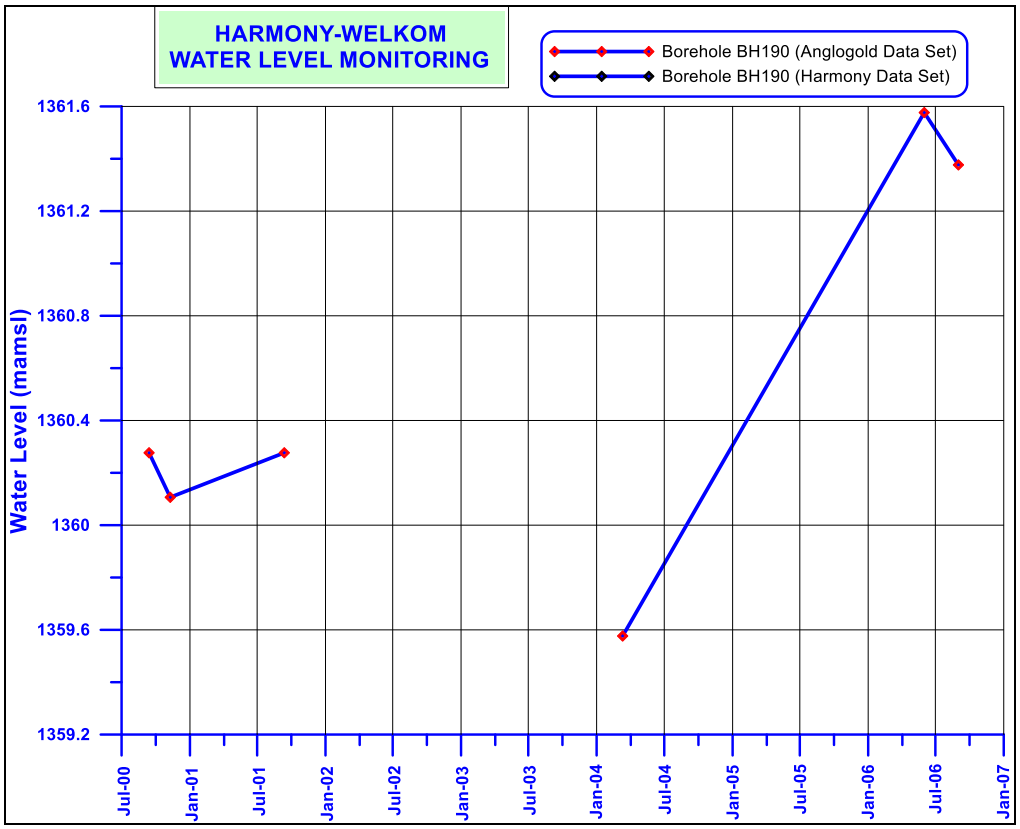

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH186 (Anglogold Data Set)
Borehole BH186 (Harmony Data Set)
Water Level (mamsl)
1348
1347
1346
1345
1344
1343
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12

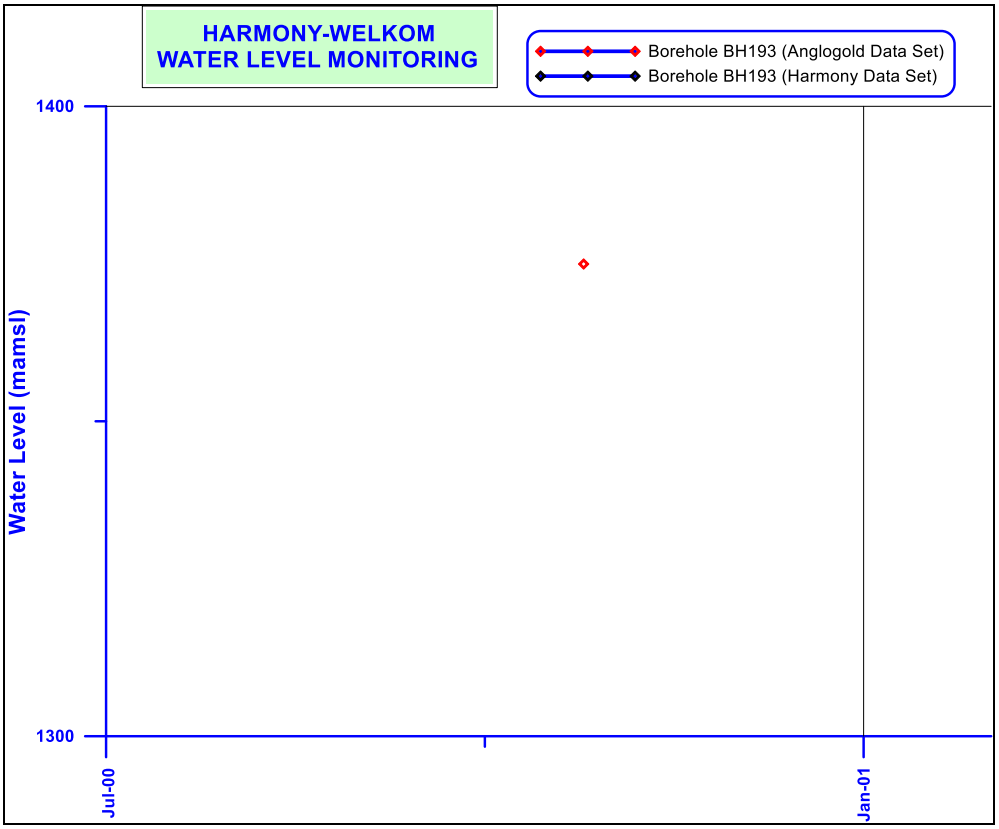

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH187 (Anglogold Data Set)
Borehole BH187 (Harmony Data Set)
Water Level (mamsl)
1348.8
1348.4
1348
1347.6
1347.2
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13

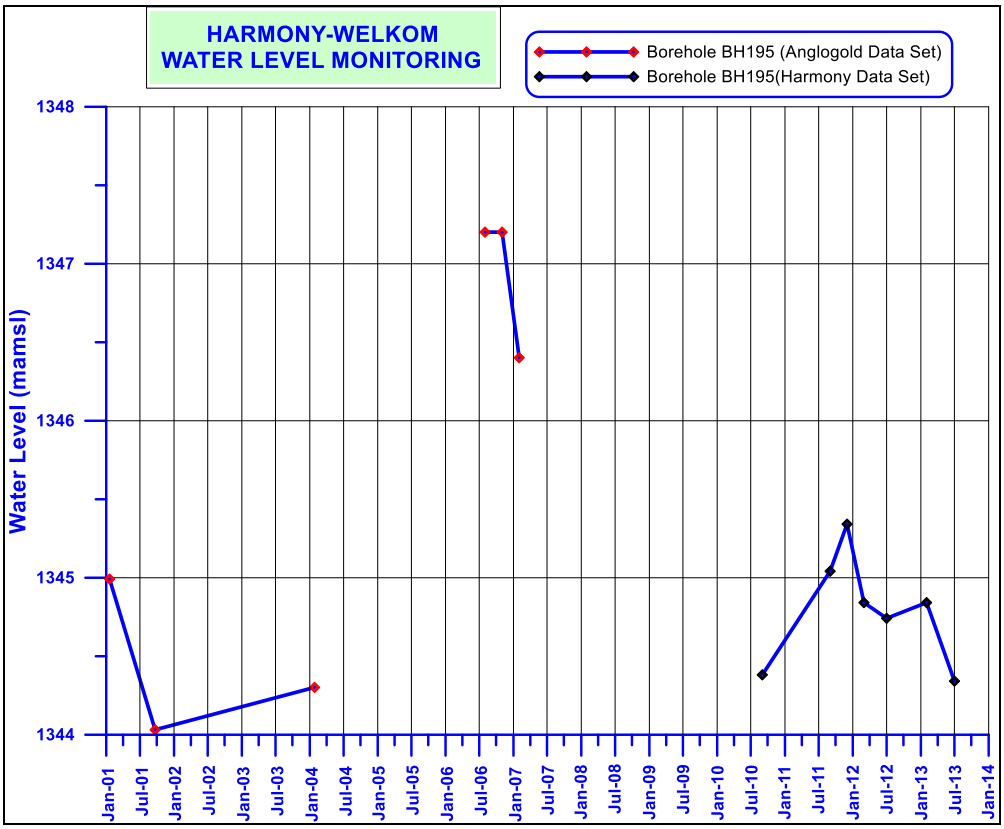

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH188 (Anglogold Data Set)
Borehole BH188 (Harmony Data Set)
Water Level (mamsl)
1348.4
1348
1347.6
1347.2
1346.8
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

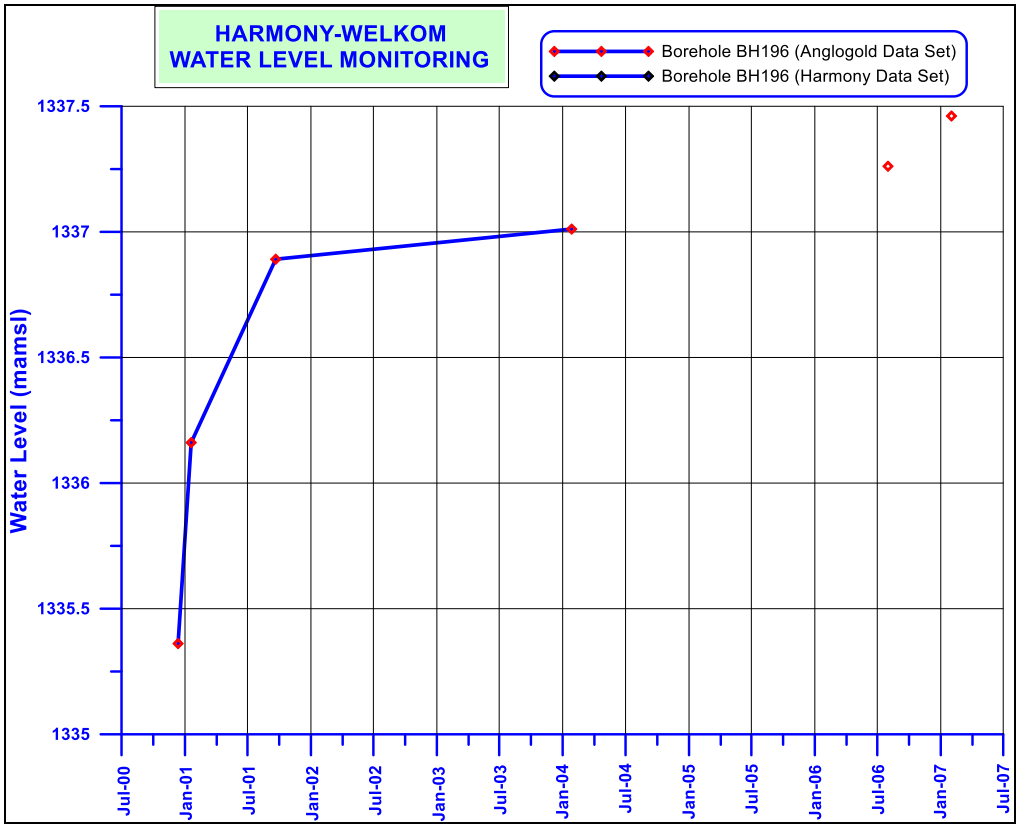

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH189 (Anglogold Data Set)
Borehole BH189 (Harmony Data Set)
Water Level (mamsl)
1347.6
1347.4
1347.2
1347
1346.8
1346.6
1346.4
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11

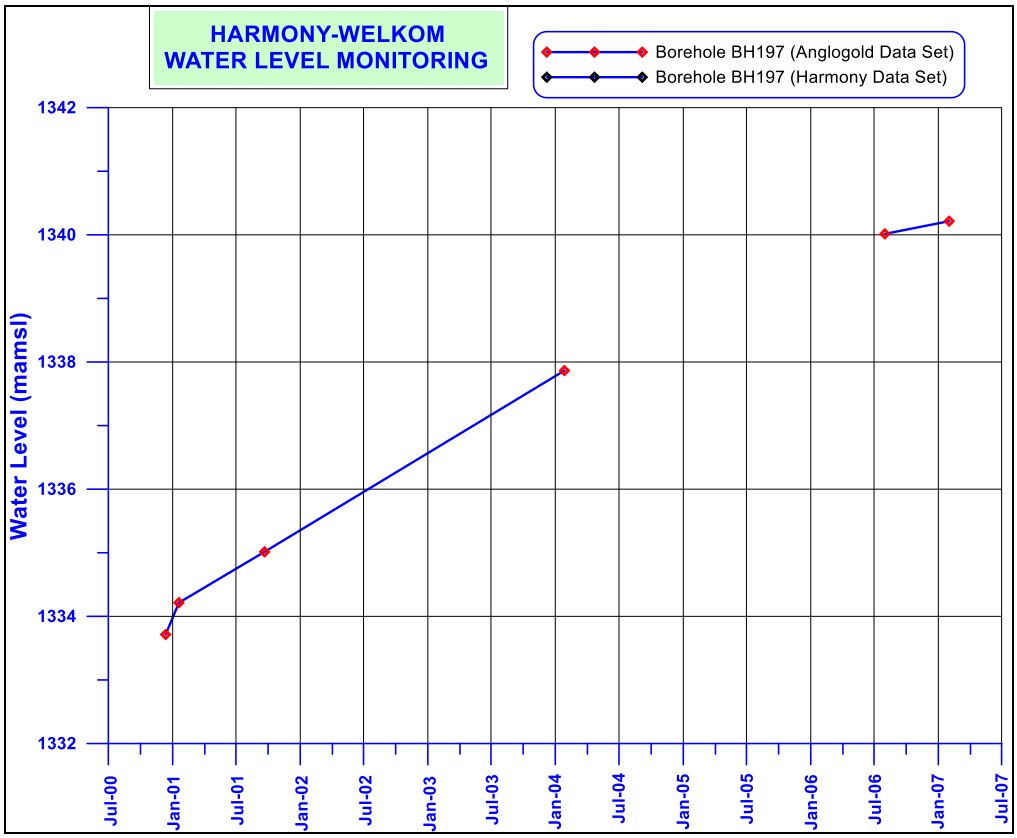

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH19 (Anglogold Data Set)
Borehole BH19 (Harmony Data Set)
Water Level (mamsl)
1364.6
1364.5
1364.4
1364.3
1364.2
1364.1
1364
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11

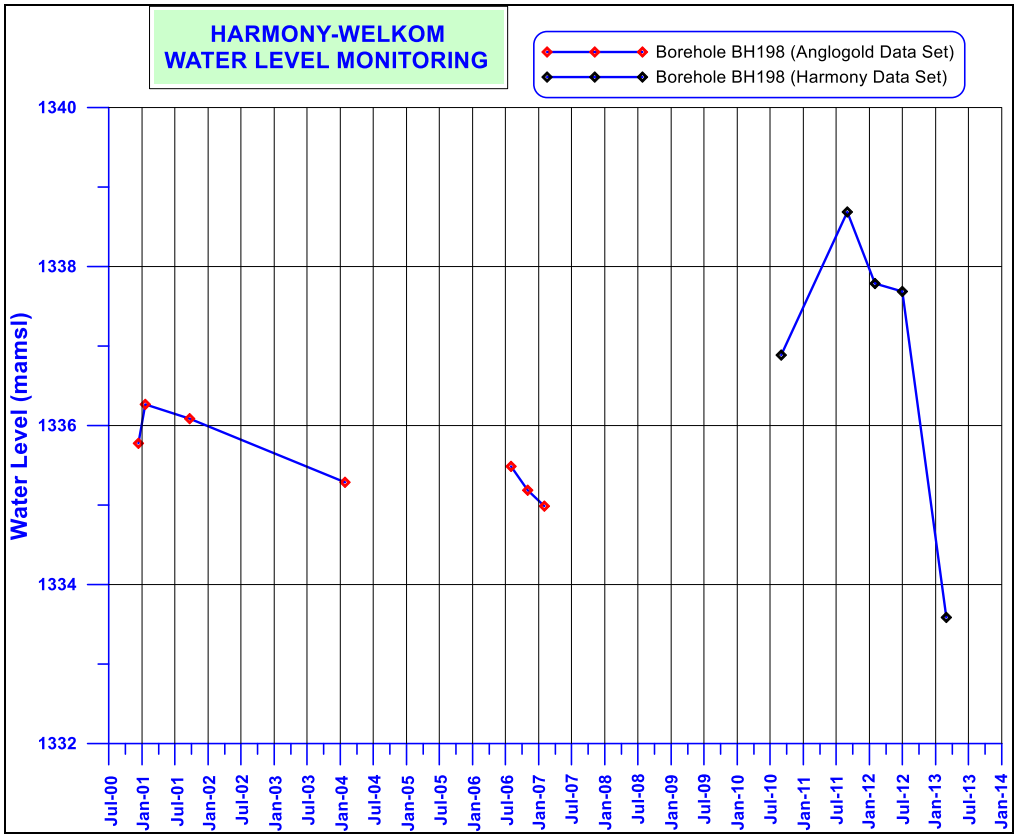

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH190 (Anglogold Data Set)
Borehole BH190 (Harmony Data Set)
Water Level (mamsl)
1361.6
1361.2
1360.8
1360.4
1360
1359.6
1359.2
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07

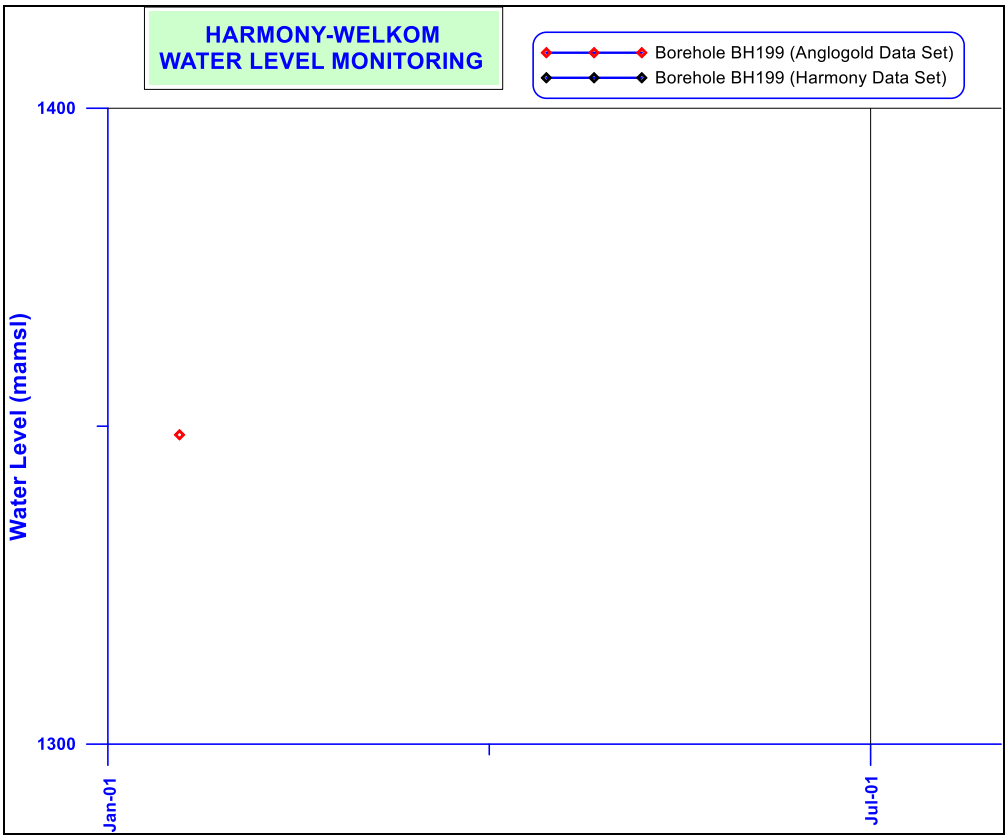

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH193 (Anglogold Data Set)
Borehole BH193 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jul-00
Jan-01

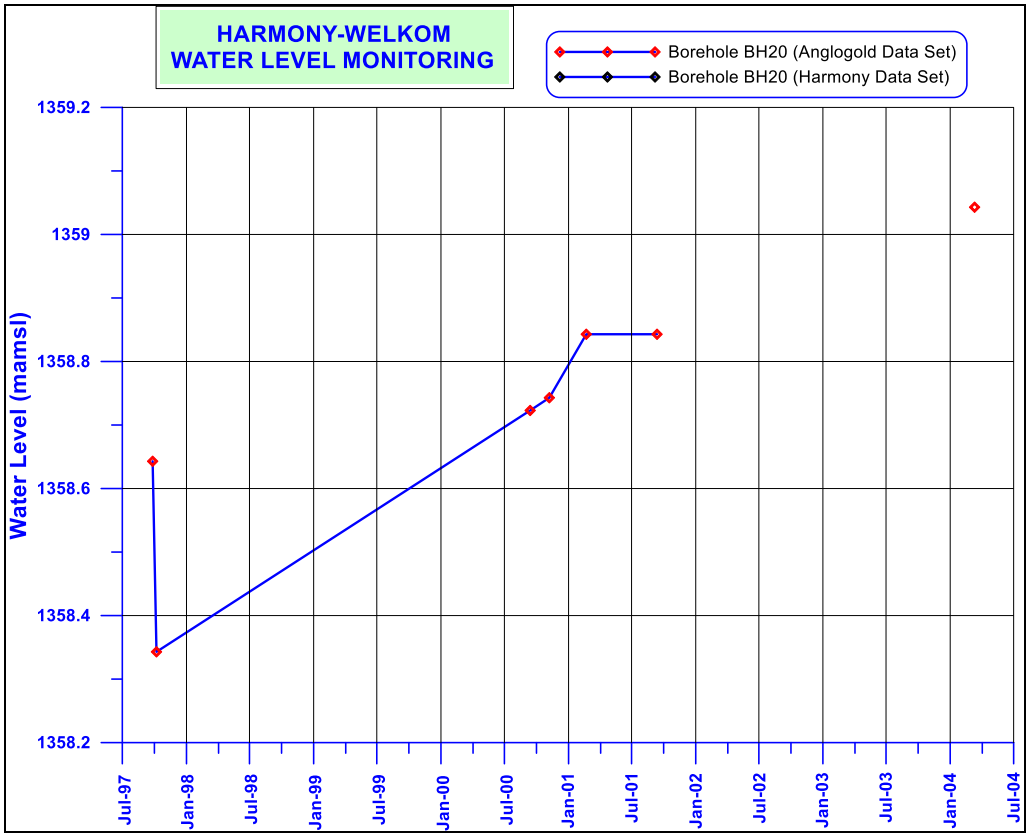

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH195 (Anglogold Data Set)
Borehole BH195(Harmony Data Set)
Water Level (mamsl)
1348
1347
1346
1345
1344
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

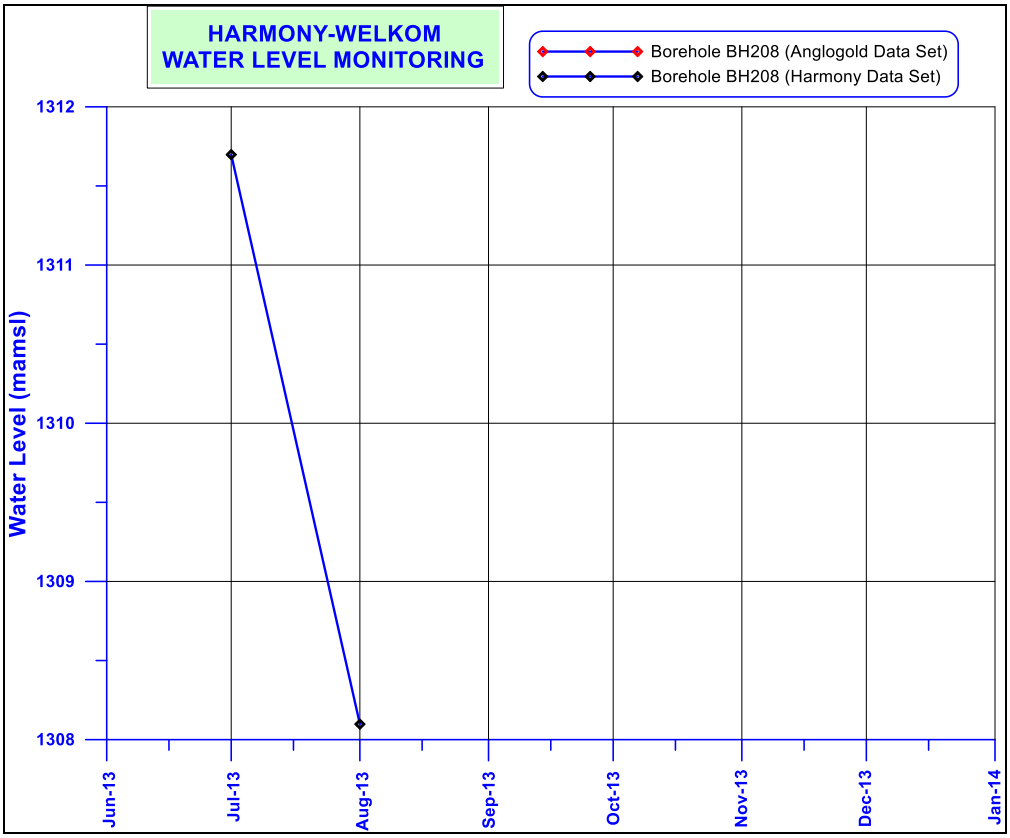

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH196 (Anglogold Data Set)
Borehole BH196 (Harmony Data Set)
Water Level (mamsl)
1337.5
1337
1336.5
1336
1335.5
1335
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

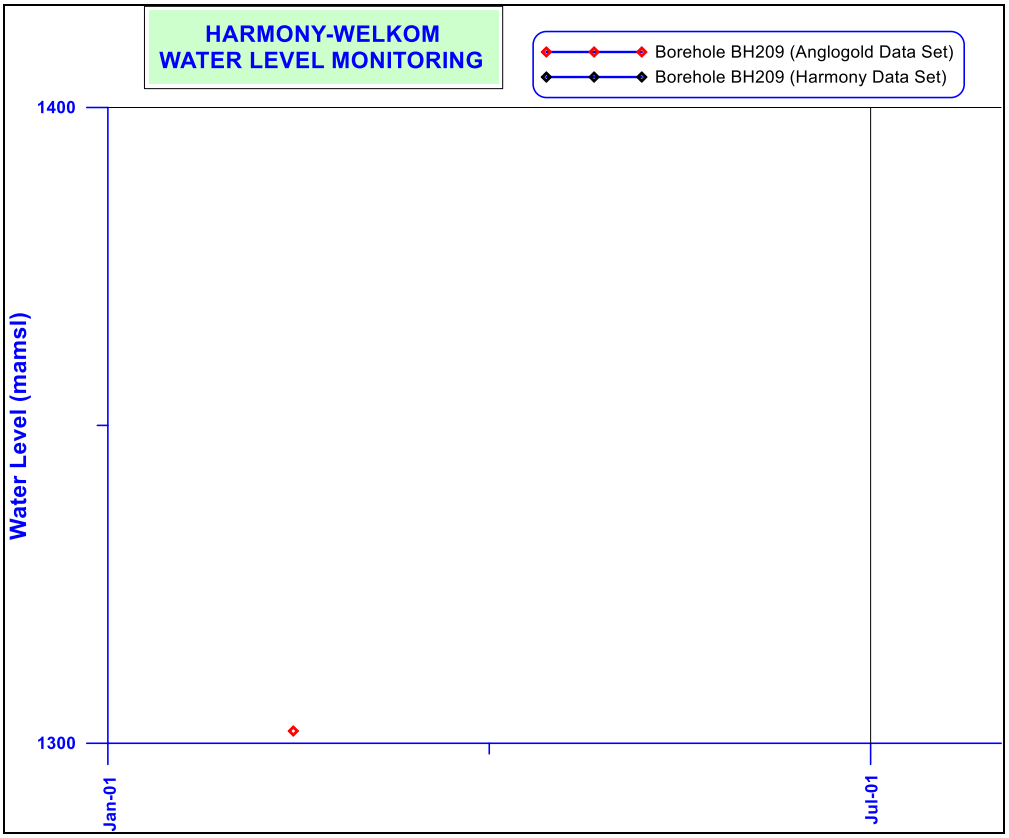

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH197 (Anglogold Data Set)
Borehole BH197 (Harmony Data Set)
Water Level (mamsl)
1342
1340
1338
1336
1334
1332
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

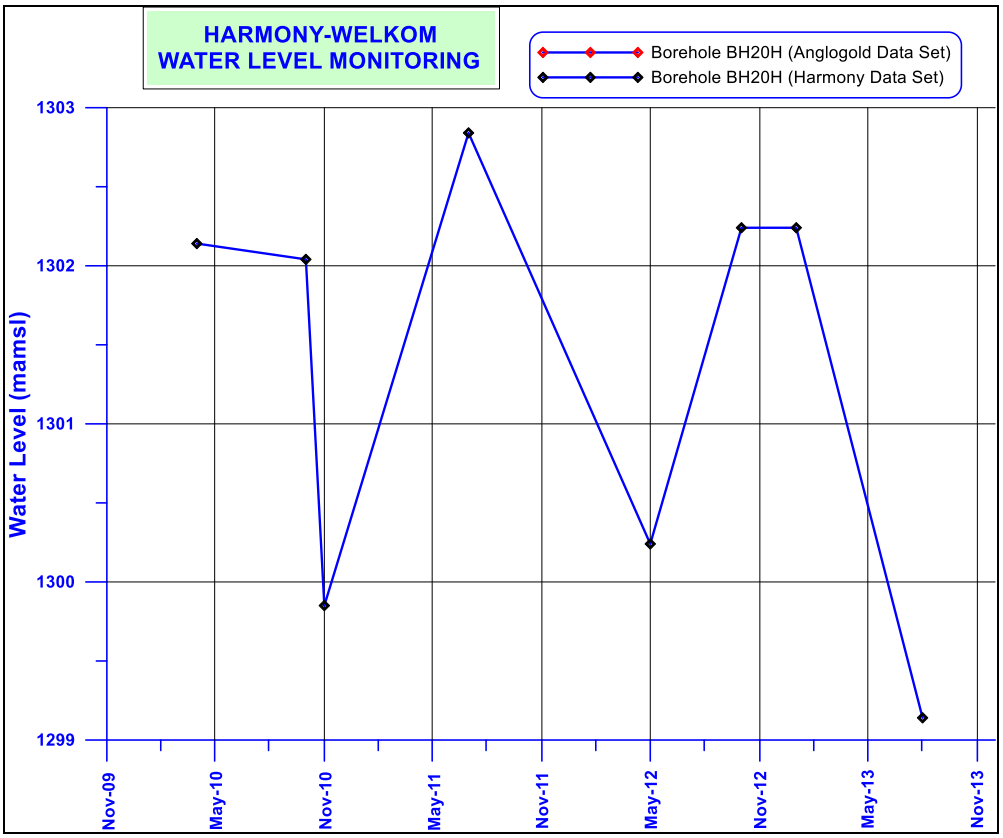

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH198 (Anglogold Data Set)
Borehole BH198 (Harmony Data Set)
Water Level (mamsl)
1340
1338
1336
1334
1332
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

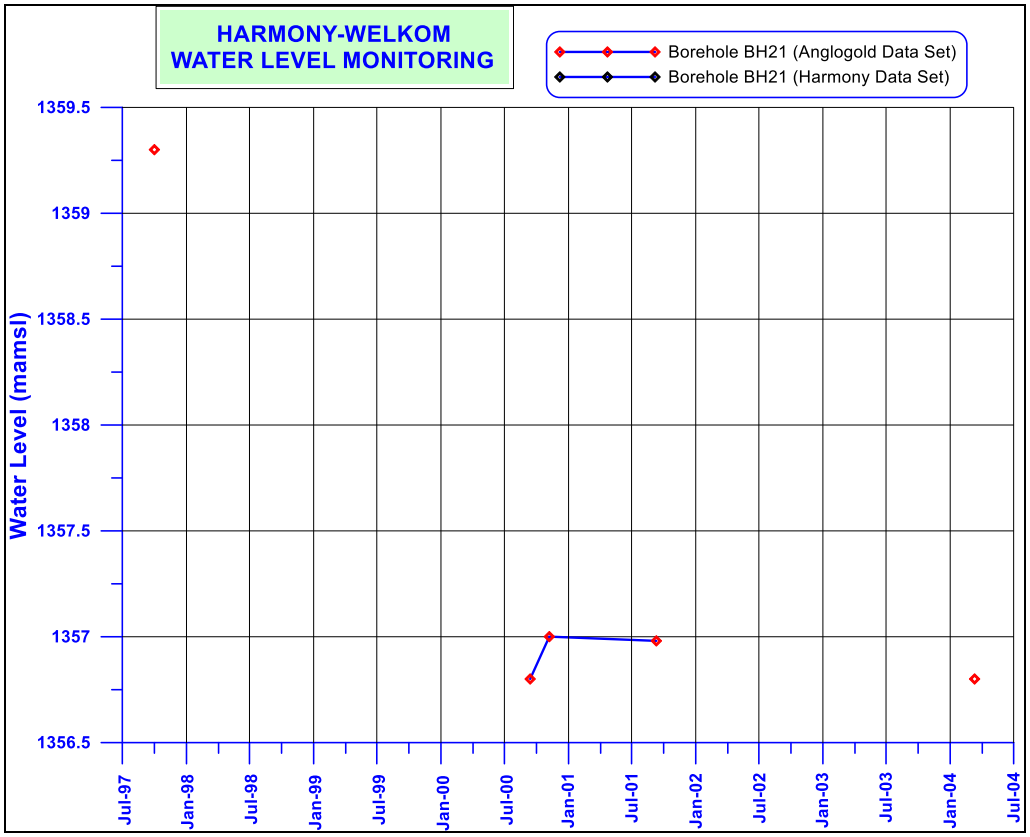

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH199 (Anglogold Data Set)
Borehole BH199 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jan-01
Jul-01

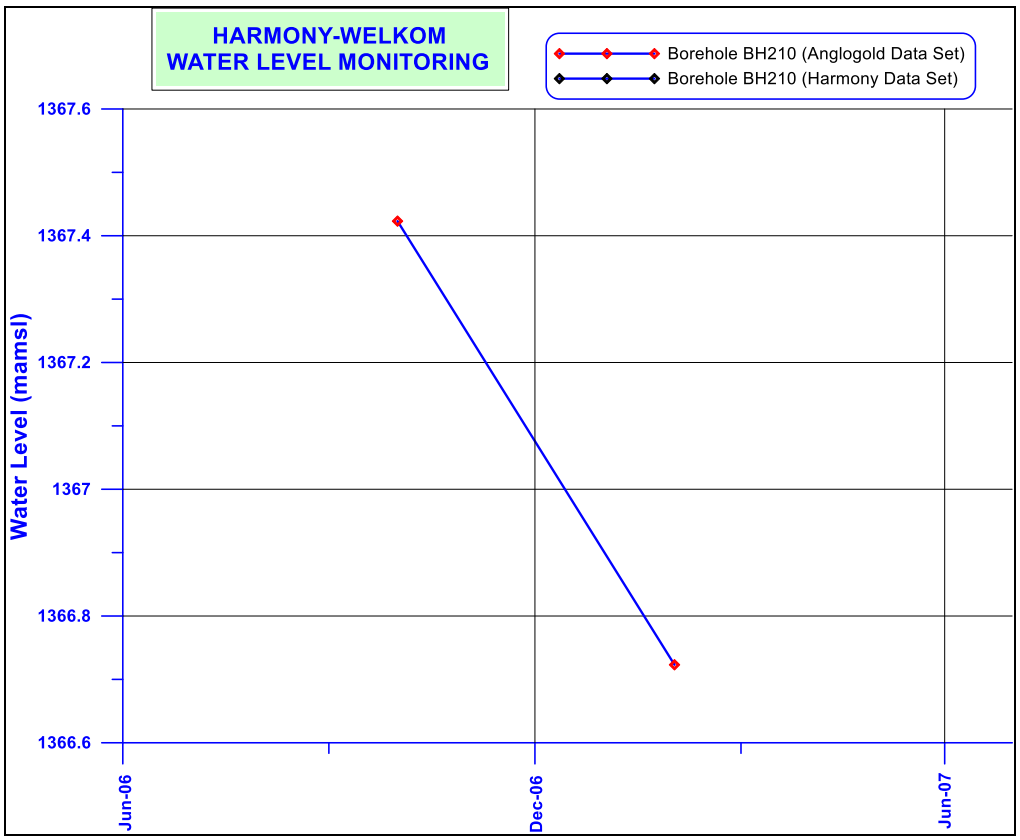

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH20 (Anglogold Data Set)
Borehole BH20 (Harmony Data Set)
Water Level (mamsl)
1359.2
1359
1358.8
1358.6
1358.4
1358.2
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04

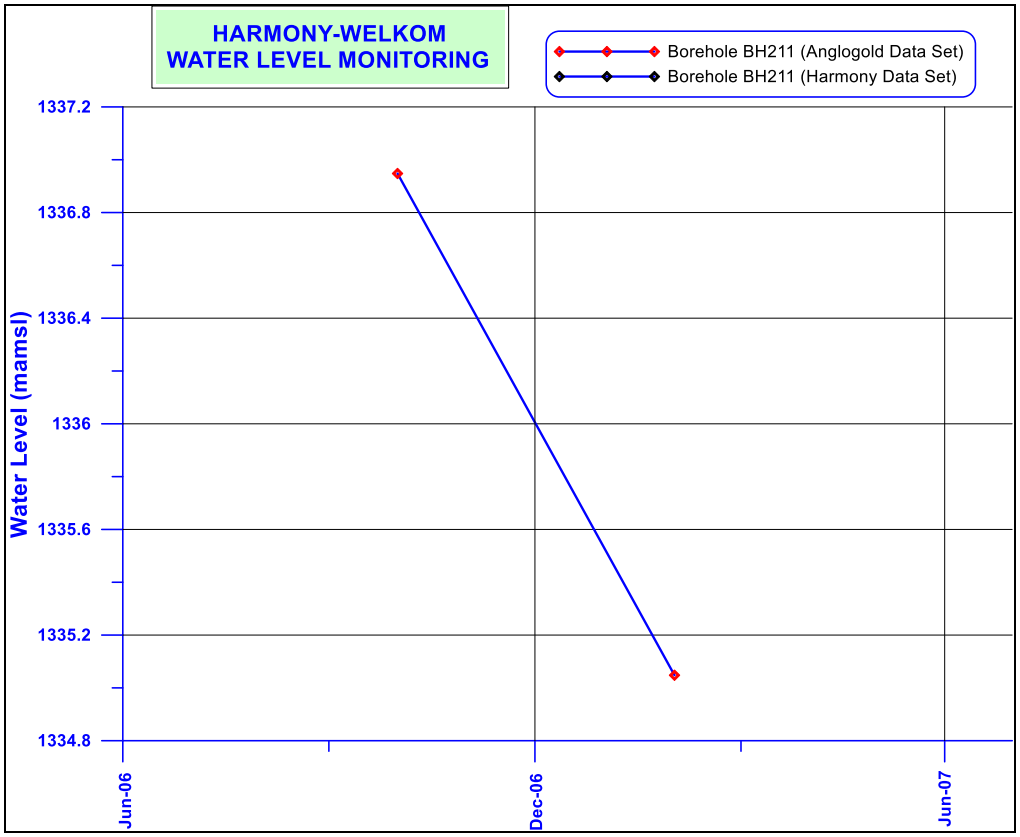

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH208 (Anglogold Data Set)
Borehole BH208 (Harmony Data Set)
Water Level (mamsl)
1312
1311
1310
1309
1308
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13
Nov-13
Dec-13
Jan-14

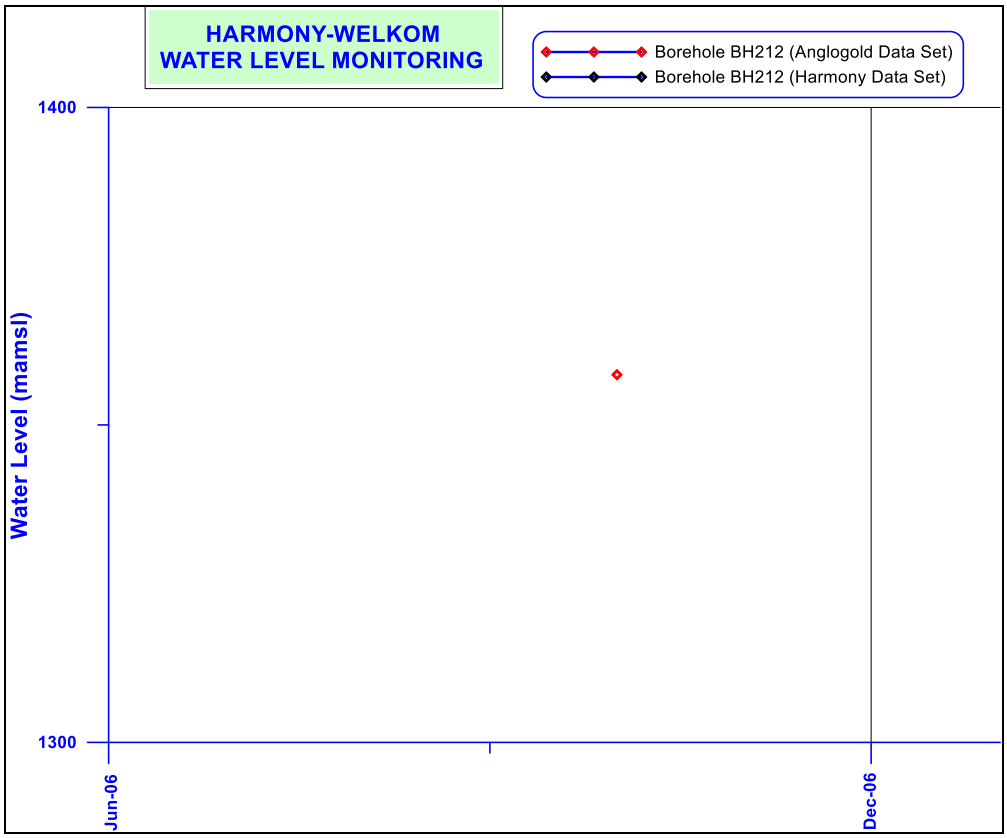

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH209 (Anglogold Data Set)
Borehole BH209 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jan-01
Jul-01

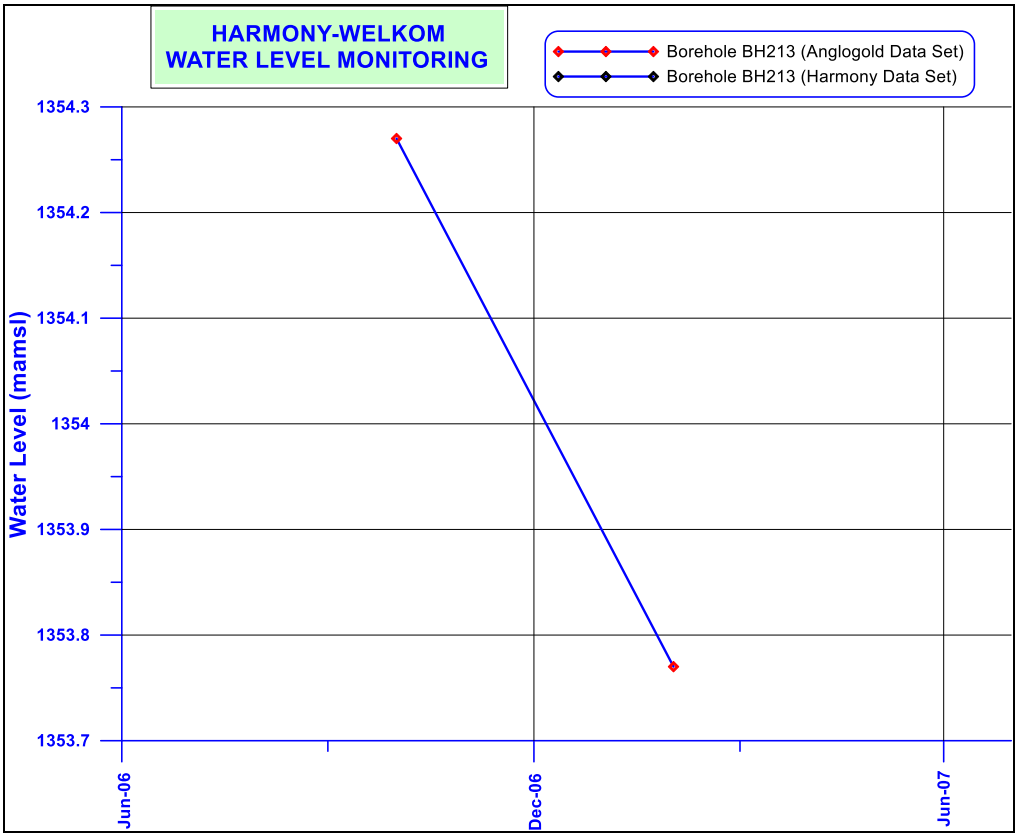

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH20H (Anglogold Data Set)
Borehole BH20H (Harmony Data Set)
Water Level (mamsl)
1303
1302
1301
1300
1299
Nov-09
May-10
Nov-10
May-11
Nov-11
May-12
Nov-12
May-13
Nov-13

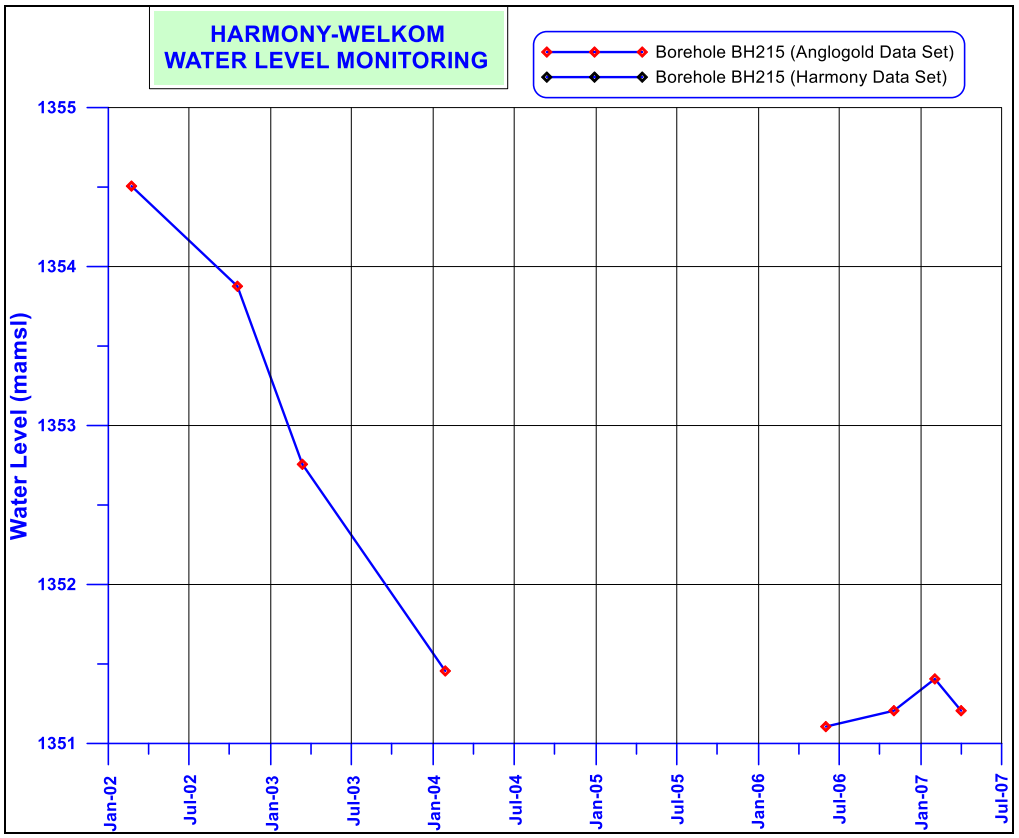

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH21 (Anglogold Data Set)
Borehole BH21 (Harmony Data Set)
Water Level (mamsl)
1359.5
1359
1358.5
1358
1357.5
1357
1356.5
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04

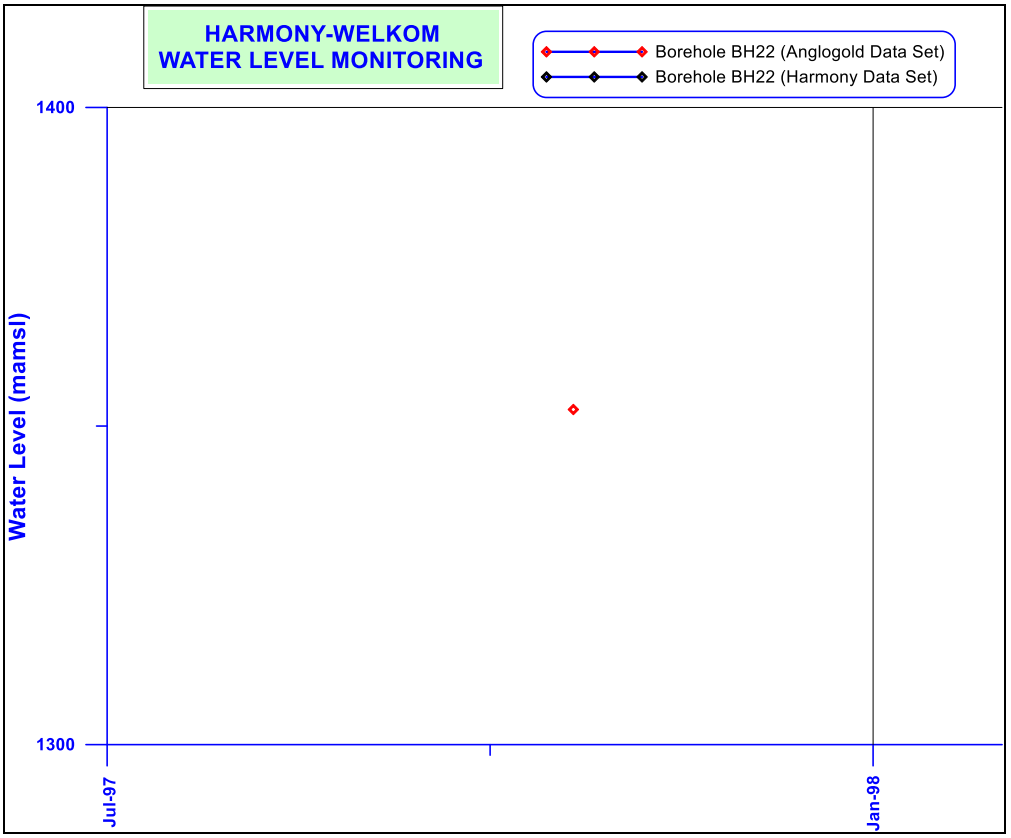

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH210 (Anglogold Data Set)
Borehole BH210 (Harmony Data Set)
Water Level (mamsl)
1367.6
1367.4
1367.2
1367
1366.8
1366.6
Jun-06
Dec-06
Jun-07

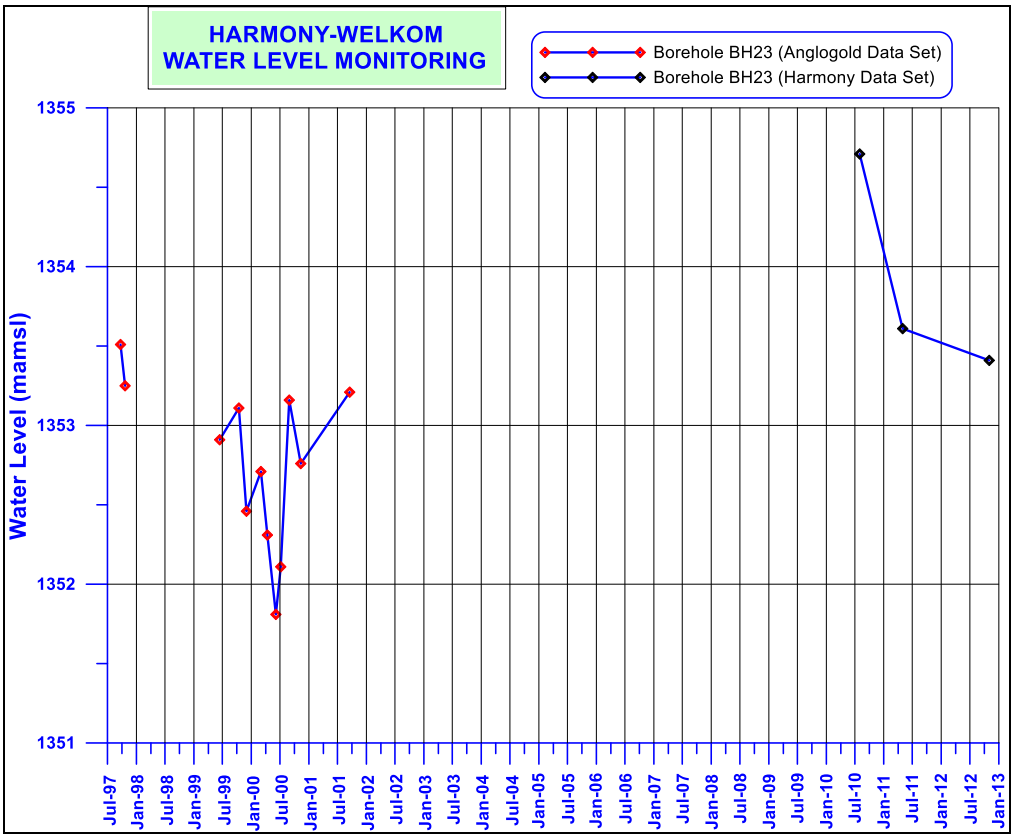

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH211 (Anglogold Data Set)
Borehole BH211 (Harmony Data Set)
Water Level (mamsl)
1337.2
1336.8
1336.4
1336
1335.6
1335.2
1334.8
Jun-06
Dec-06
Jun-07

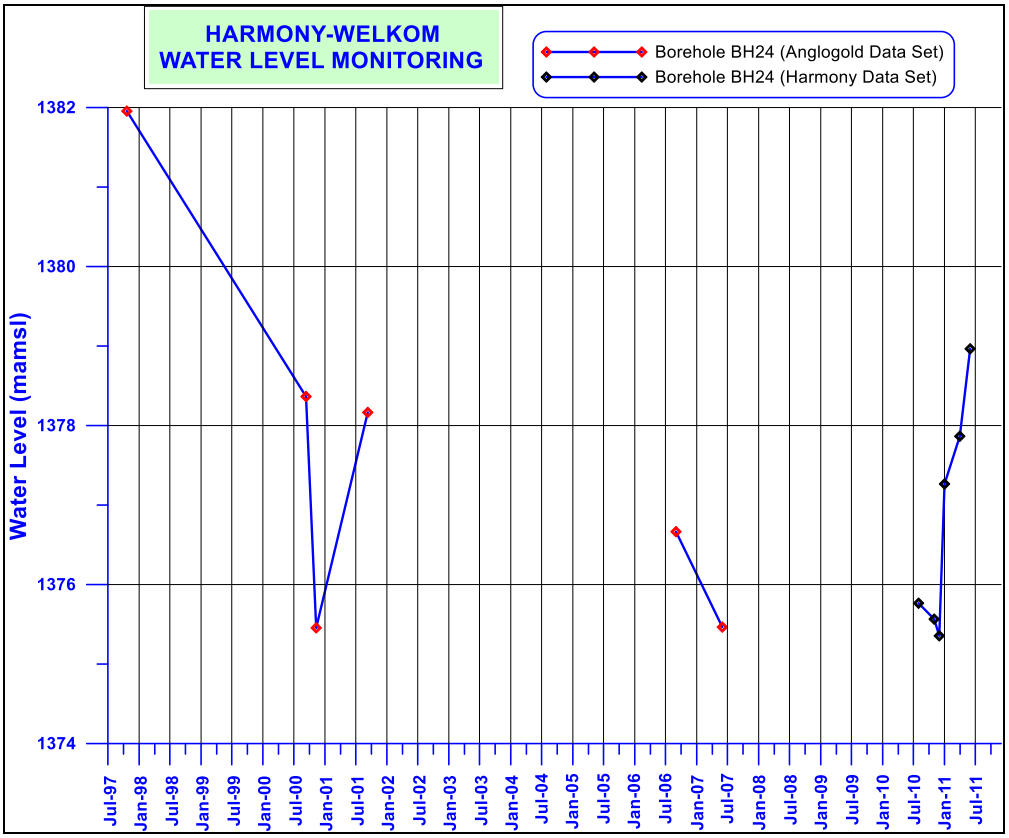

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH212 (Anglogold Data Set)
Borehole BH212 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jun-06
Dec-06

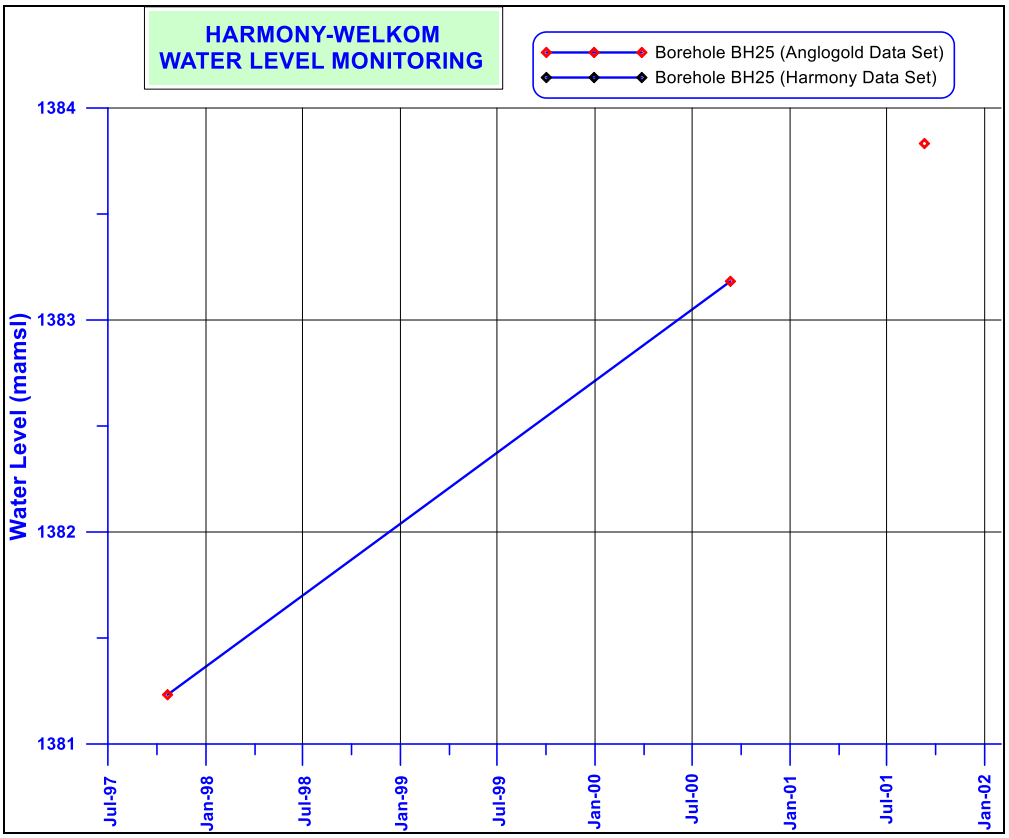

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH213 (Anglogold Data Set)
Borehole BH213 (Harmony Data Set)
Water Level (mamsl)
1354.3
1354.2
1354.1
1354
1353.9
1353.8
1353.7
Jun-06
Dec-06
Jun-07

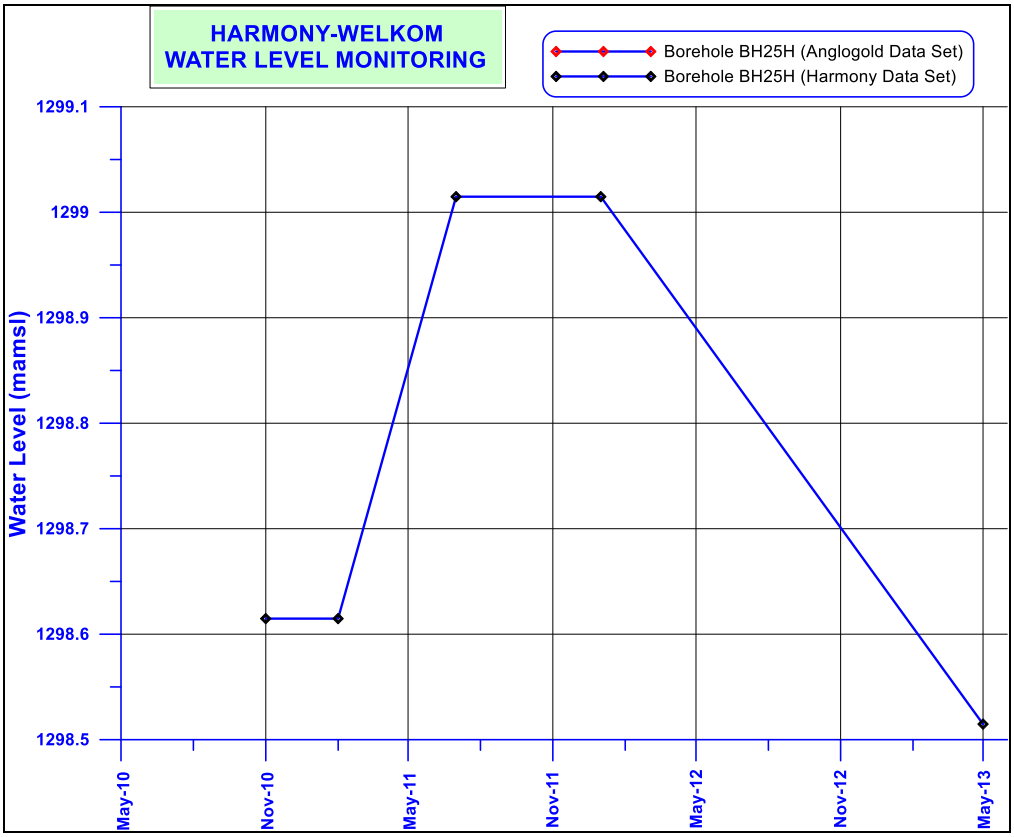

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH215 (Anglogold Data Set)
Borehole BH215 (Harmony Data Set)
Water Level (mamsl)
1355
1354
1353
1352
1351
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

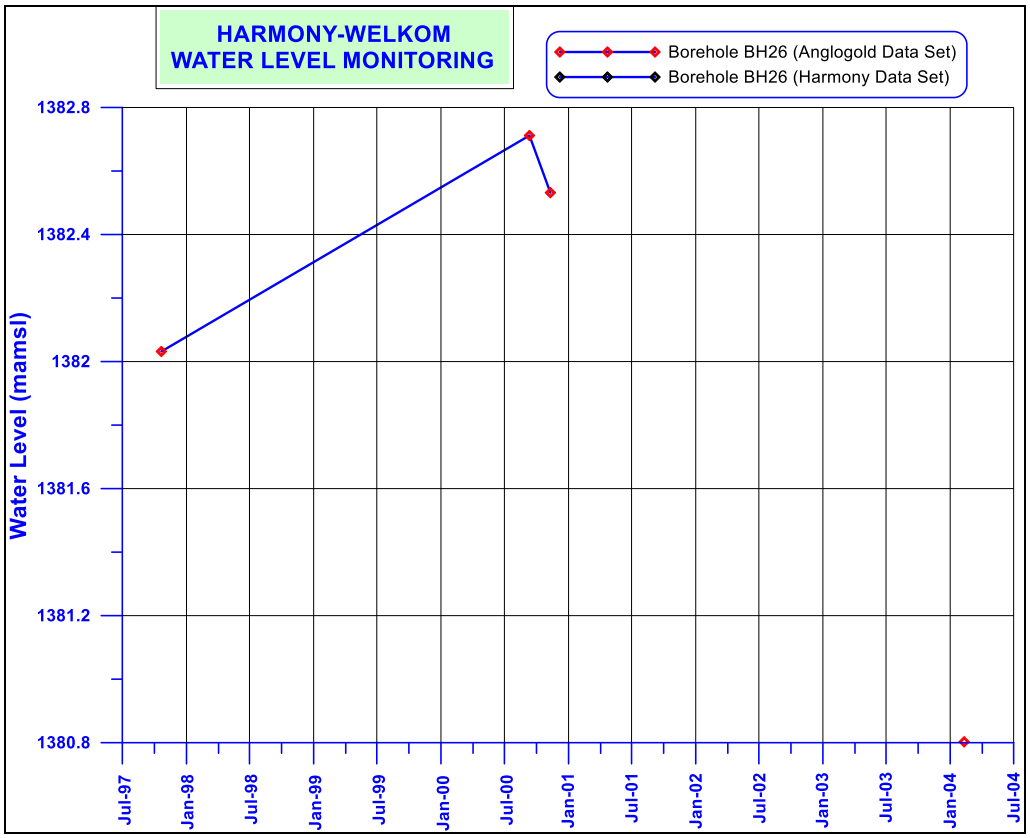

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH22 (Anglogold Data Set)
Borehole BH22 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jul-97
Jan-98

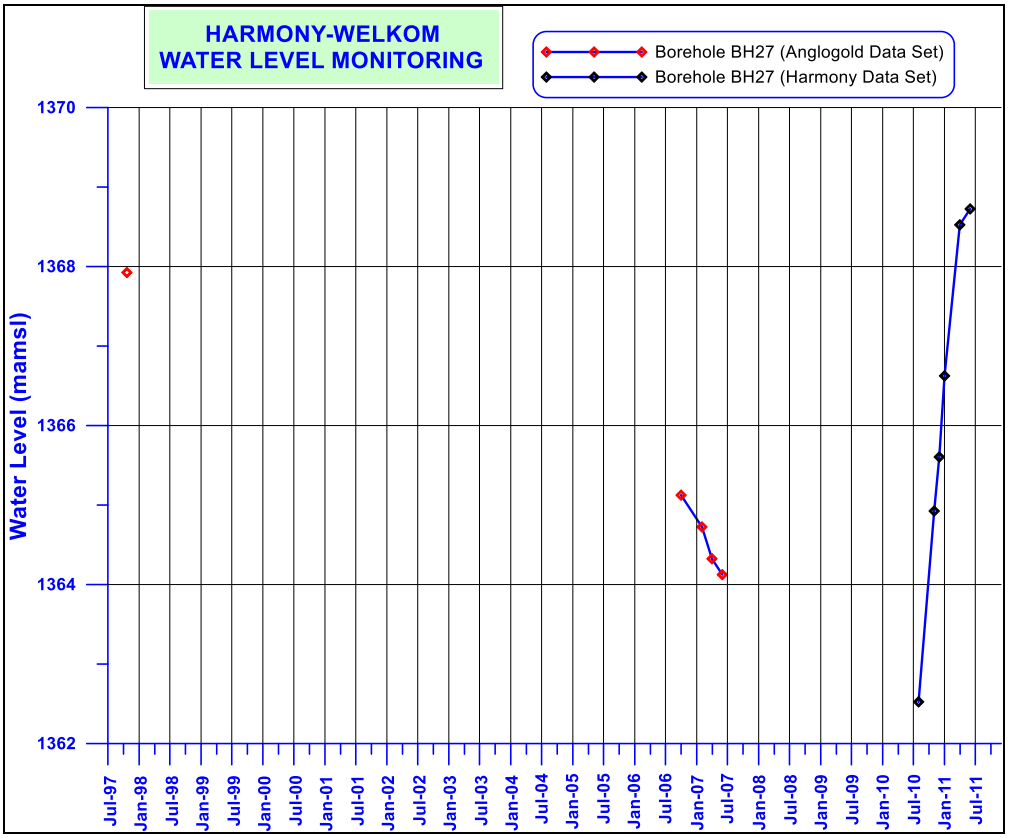

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH23 (Anglogold Data Set)
Borehole BH23 (Harmony Data Set)
Water Level (mamsl)
1355
1354
1353
1352
1351
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13

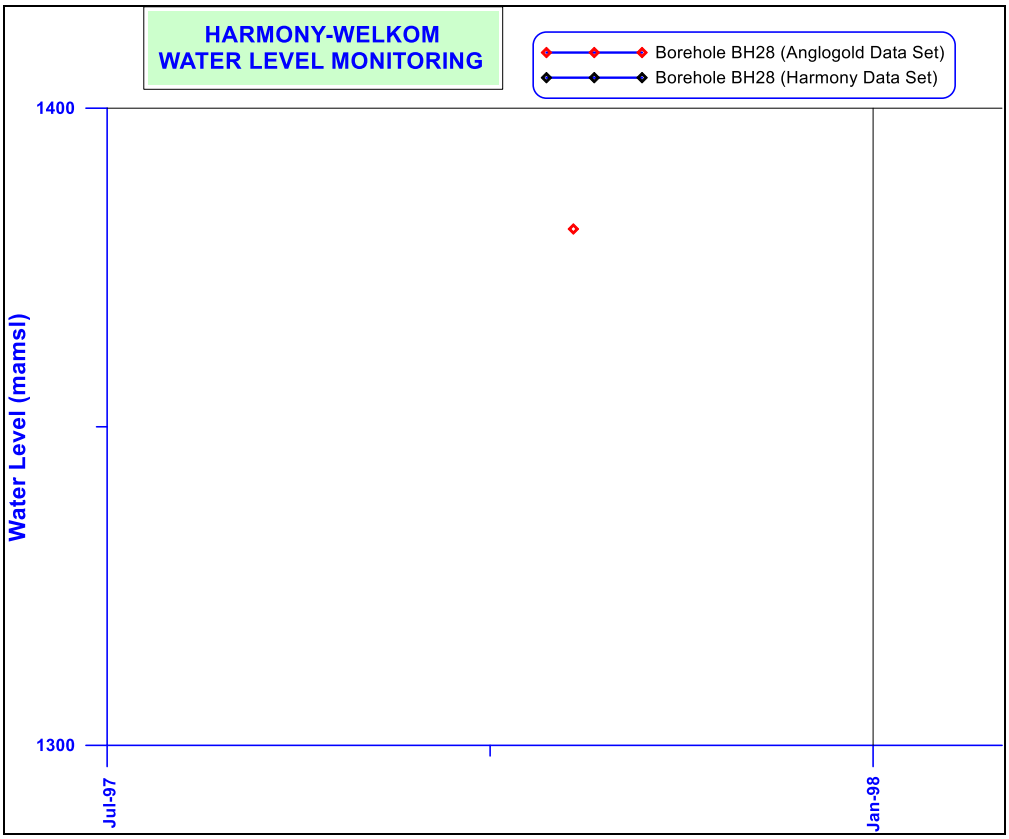

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH24 (Anglogold Data Set)
Borehole BH24 (Harmony Data Set)
Water Level (mamsl)
1382
1380
1378
1376
1374
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11

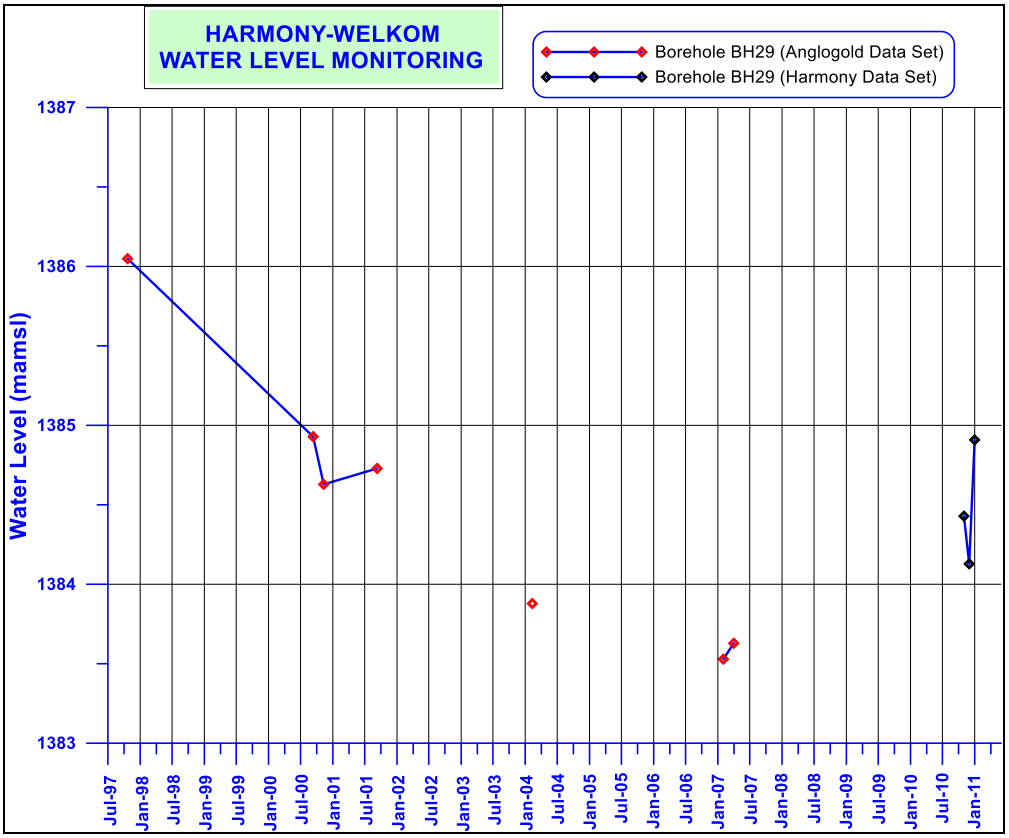

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH25 (Anglogold Data Set)
Borehole BH25 (Harmony Data Set)
Water Level (mamsl)
1384
1383
1382
1381
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02

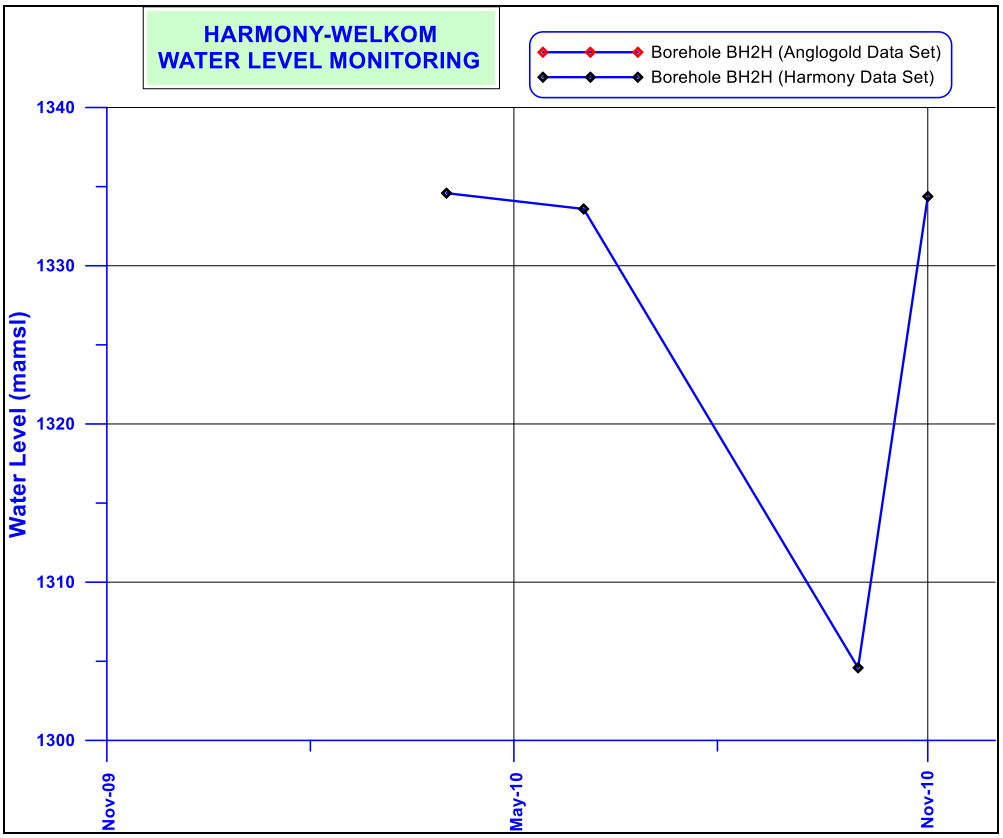

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH25H (Anglogold Data Set)
Borehole BH25H (Harmony Data Set)
Water Level (mamsl)
1299.1
1299
1298.9
1298.8
1298.7
1298.6
1298.5
May-10
Nov-10
May-11
Nov-11
May-12
Nov-12
May-13

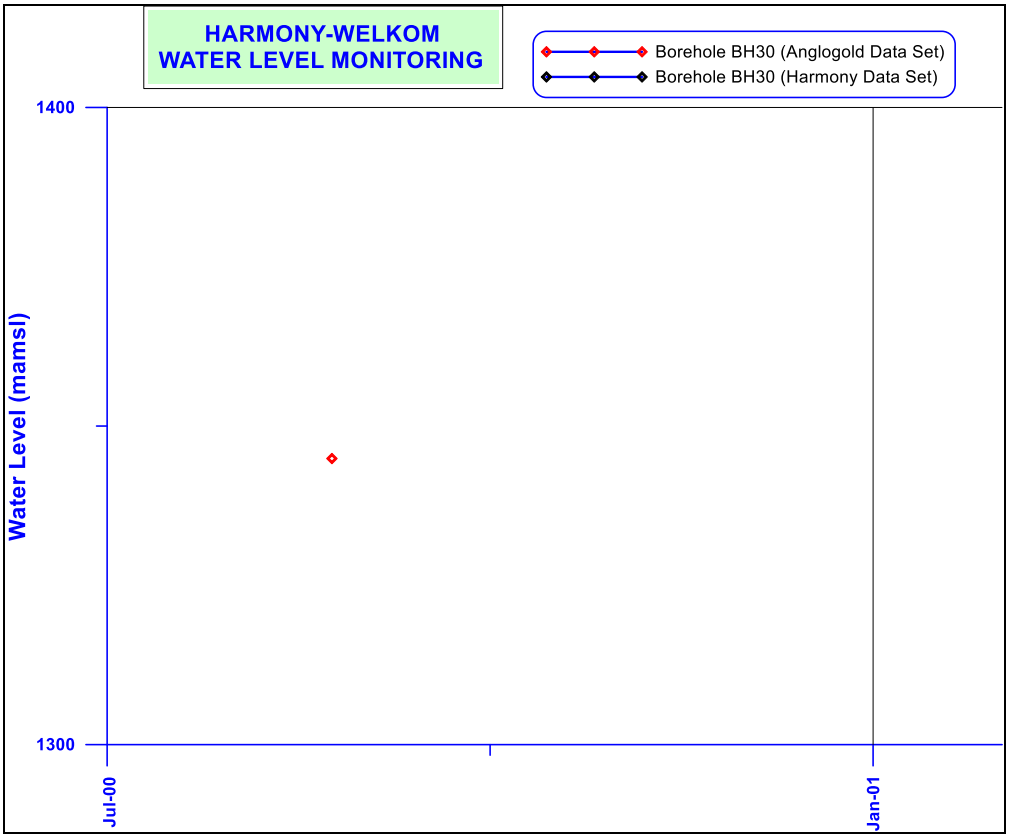

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH26 (Anglogold Data Set)
Borehole BH26 (Harmony Data Set)
Water Level (mamsl)
1382.8
1382.4
1382
1381.6
1381.2
1380.8
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04

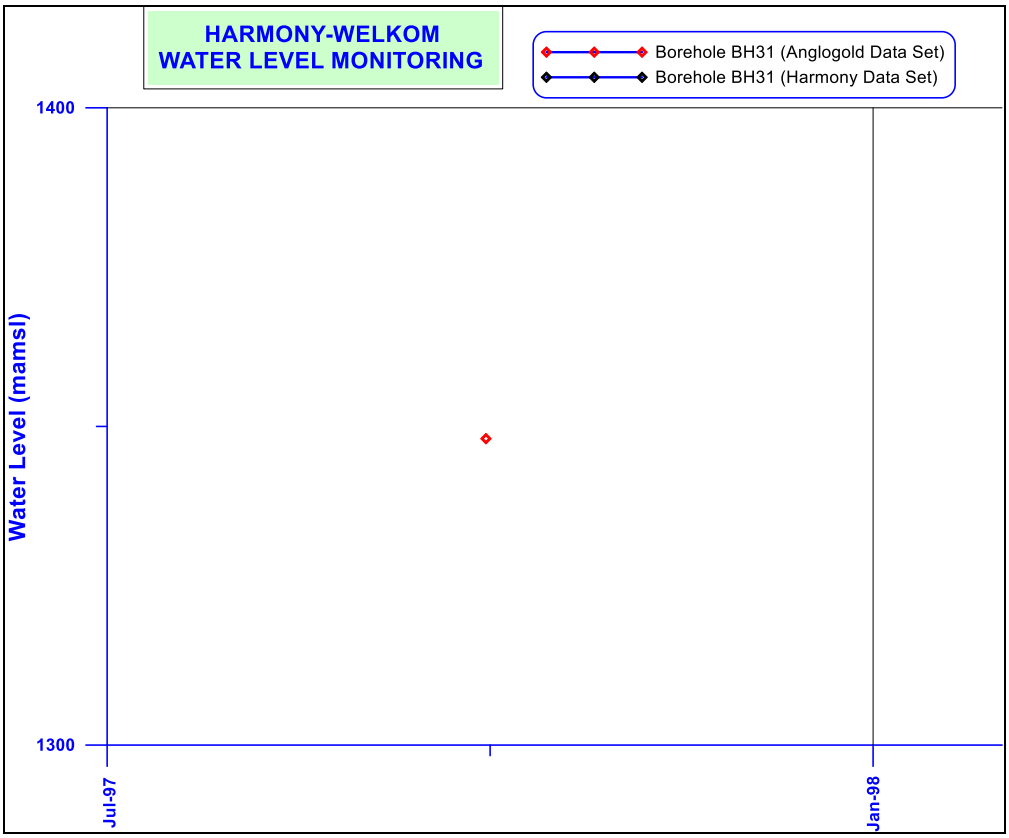

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH27 (Anglogold Data Set)
Borehole BH27 (Harmony Data Set)
Water Level (mamsl)
1370
1368
1366
1364
1362
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11

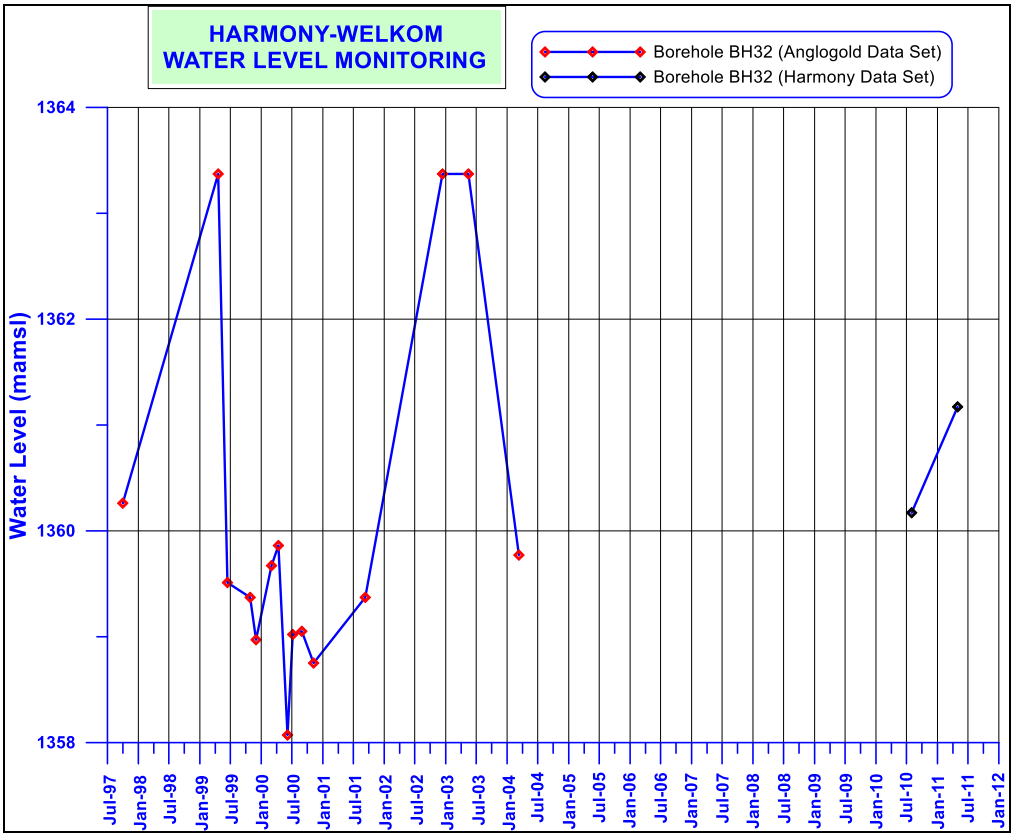

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH28 (Anglogold Data Set)
Borehole BH28 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jul-97
Jan-98

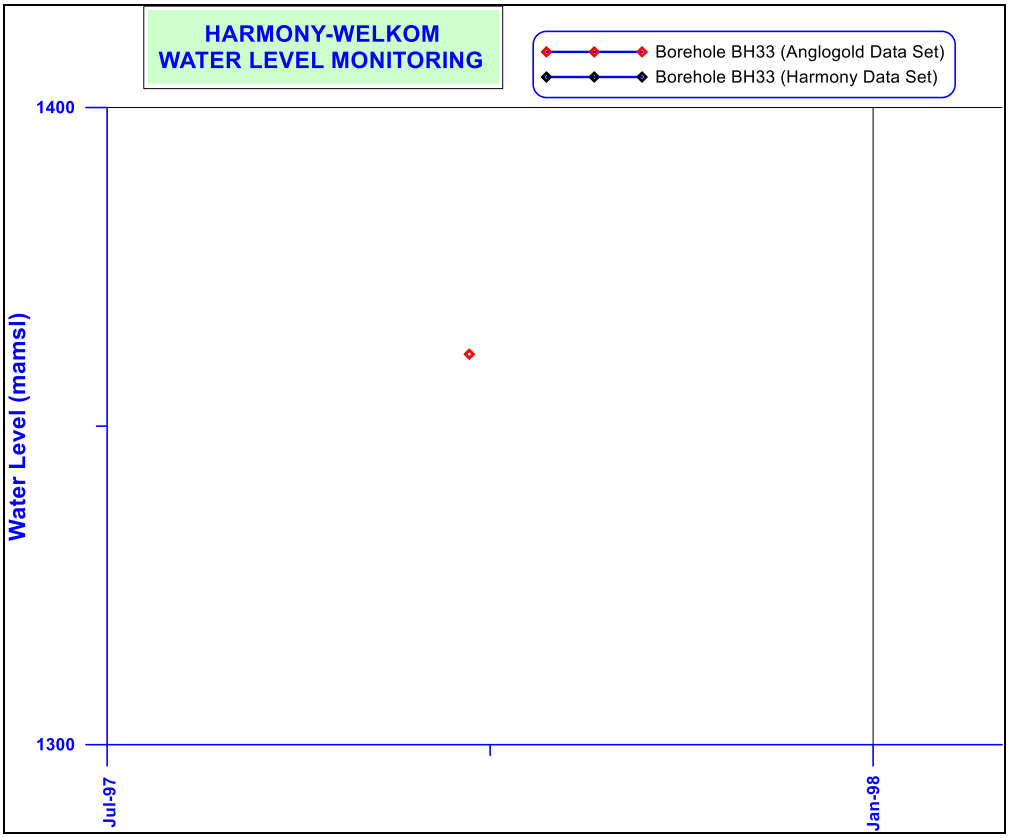

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH29 (Anglogold Data Set)
Borehole BH29 (Harmony Data Set)
Water Level (mamsl)
1387
1386
1385
1384
1383
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11

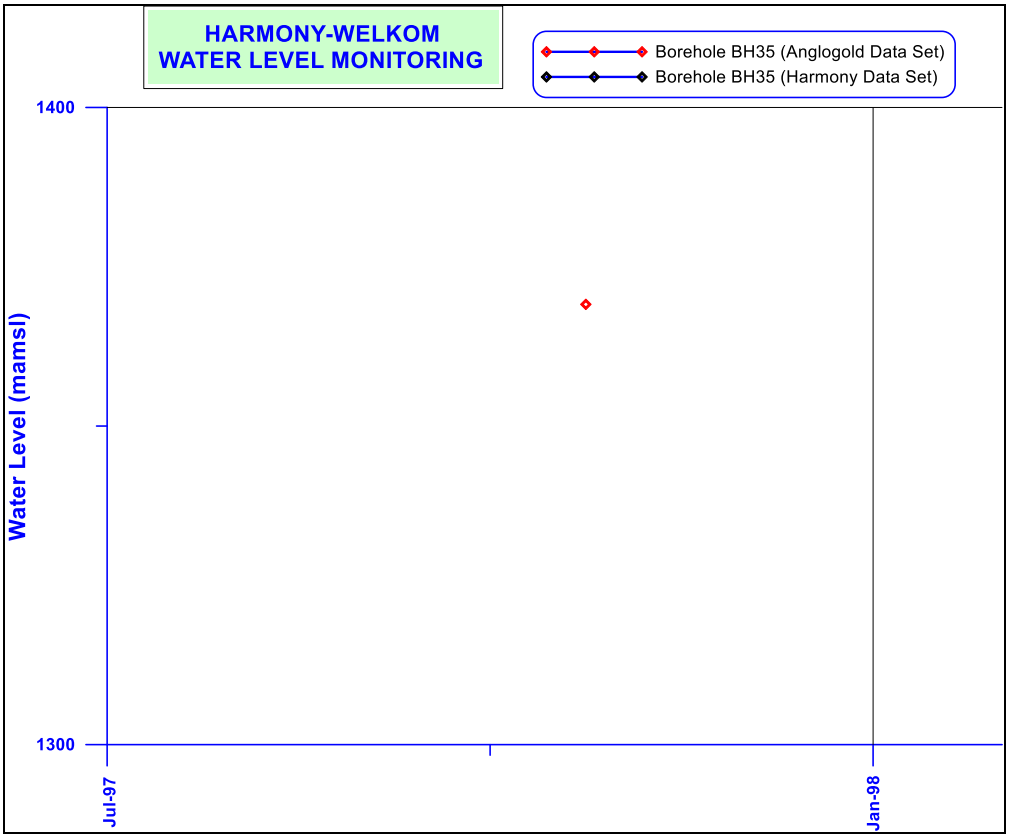

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH2H (Anglogold Data Set)
Borehole BH2H (Harmony Data Set)
Water Level (mamsl)
1340
1330
1320
1310
1300
Nov-09
May-10
Nov-10

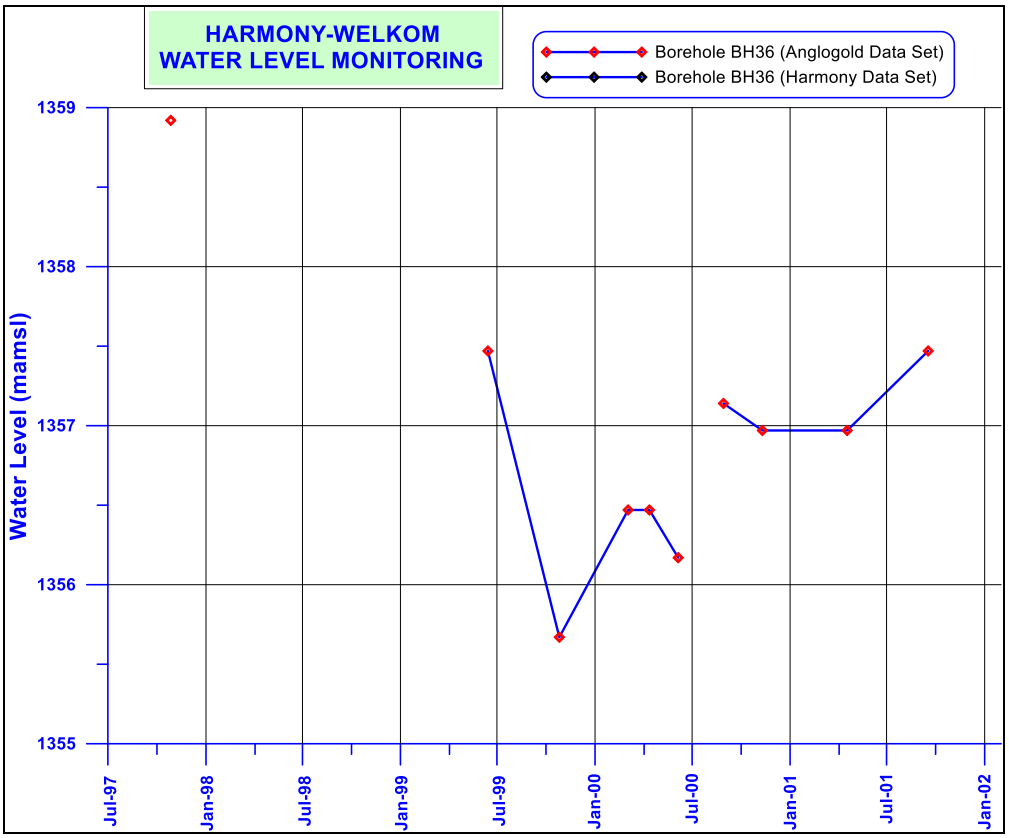

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH30 (Anglogold Data Set)
Borehole BH30 (Harmony Data Set)
1400
1300
Water Level (mamsl)
Jul-00
Jan-01

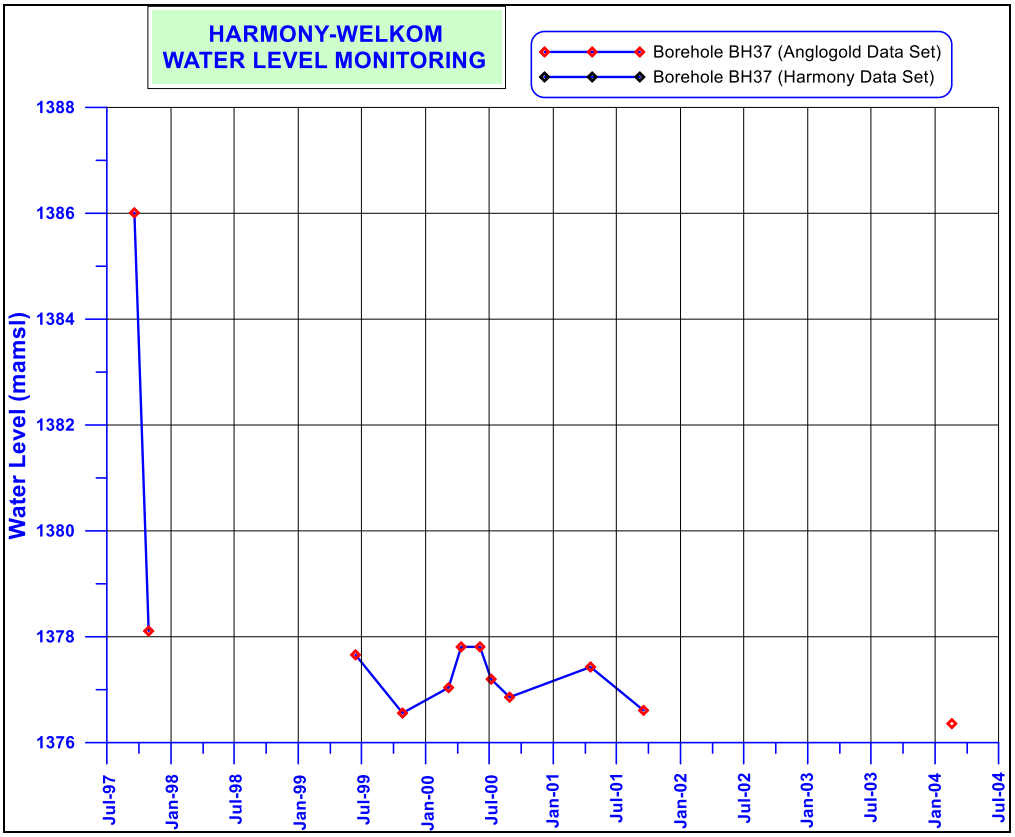

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH31 (Anglogold Data Set)
Borehole BH31 (Harmony Data Set)
1400
1300
Water Level (mamsl)
Jul-97
Jan-98

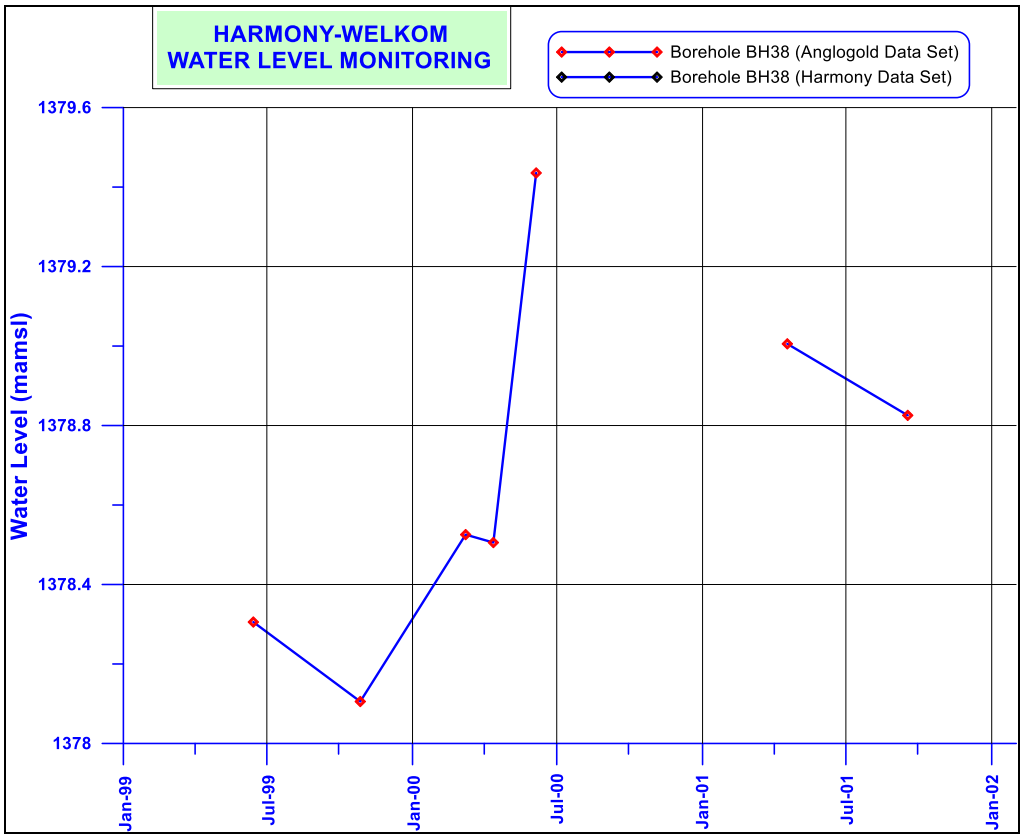

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH32 (Anglogold Data Set)
Borehole BH32 (Harmony Data Set)
Water Level (mamsl)
1364
1362
1360
1358
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12

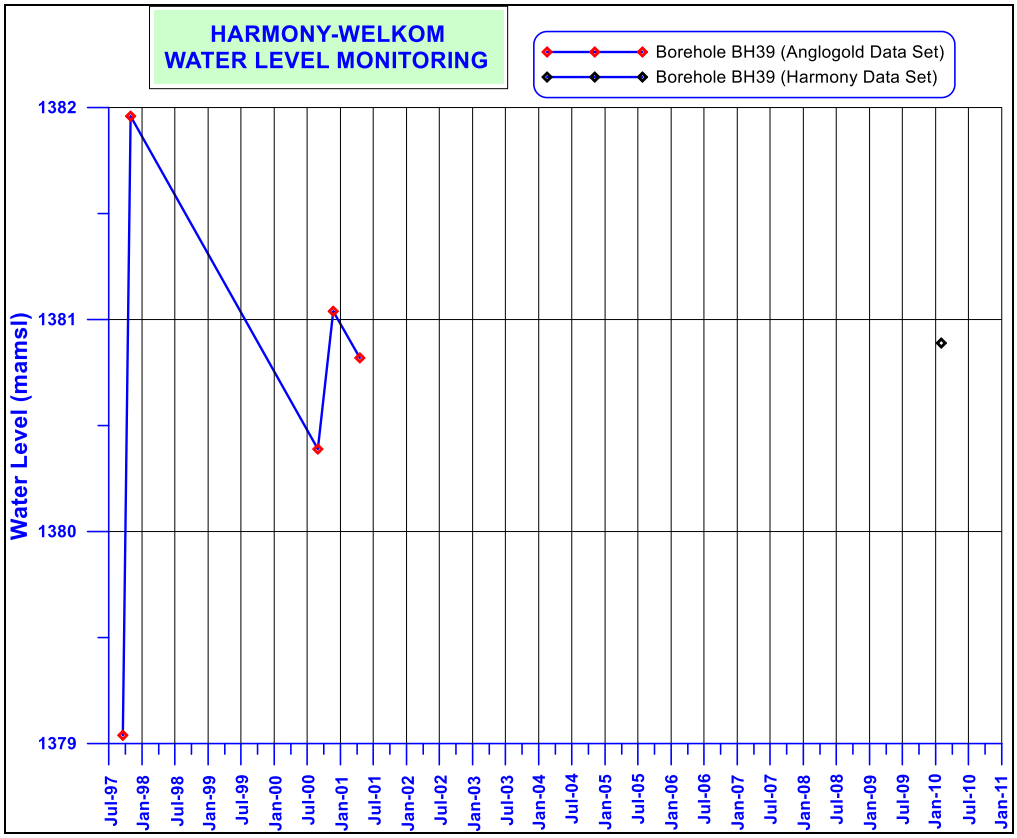

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH33 (Anglogold Data Set)
Borehole BH33 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jul-97
Jan-98

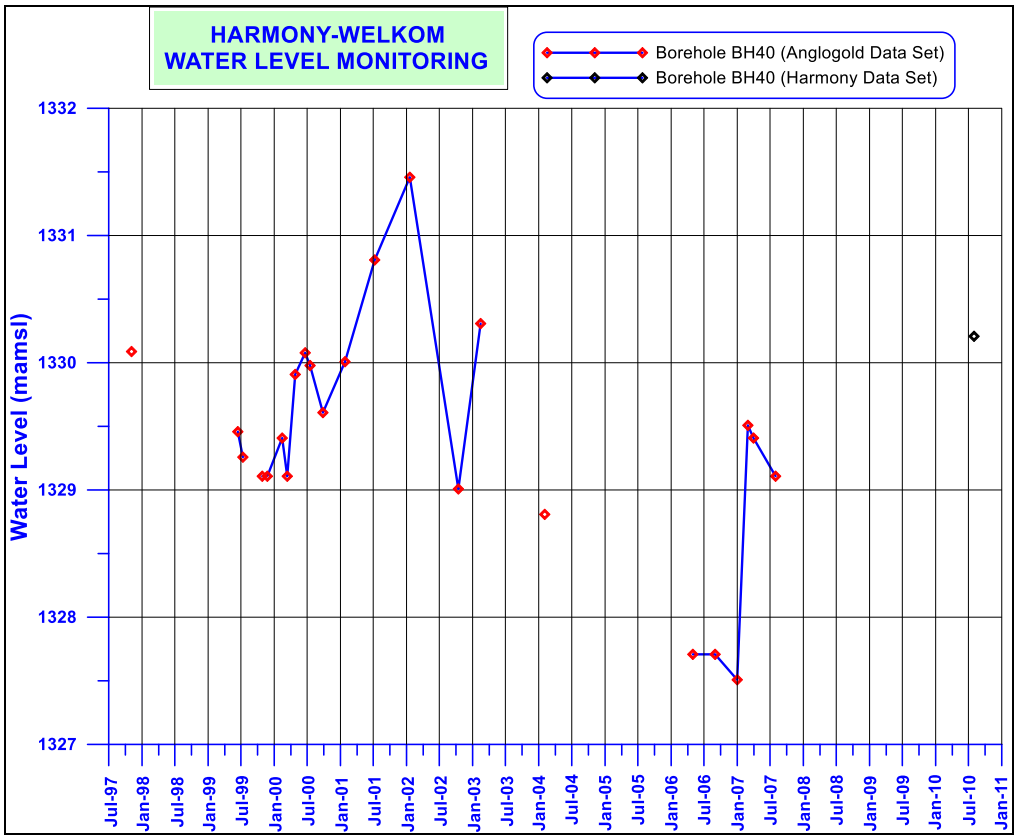

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH35 (Anglogold Data Set)
Borehole BH35 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jul-97
Jan-98

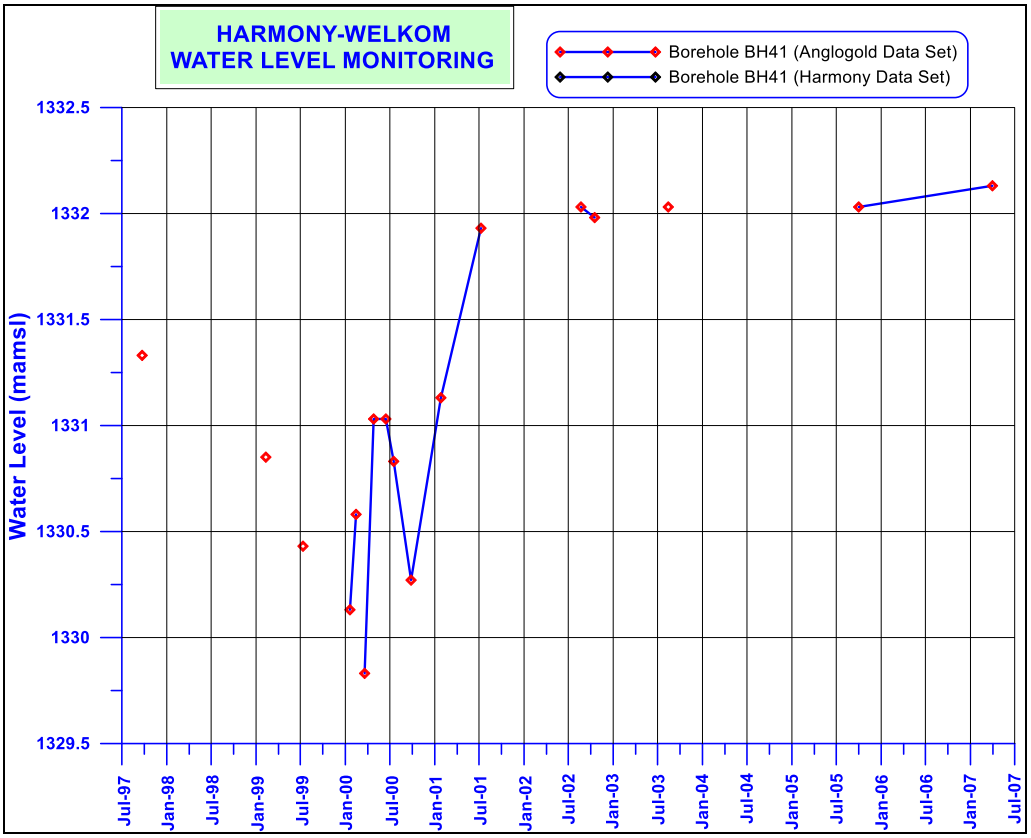

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH36 (Anglogold Data Set)
Borehole BH36 (Harmony Data Set)
Water Level (mamsl)
1359
1358
1357
1356
1355
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02

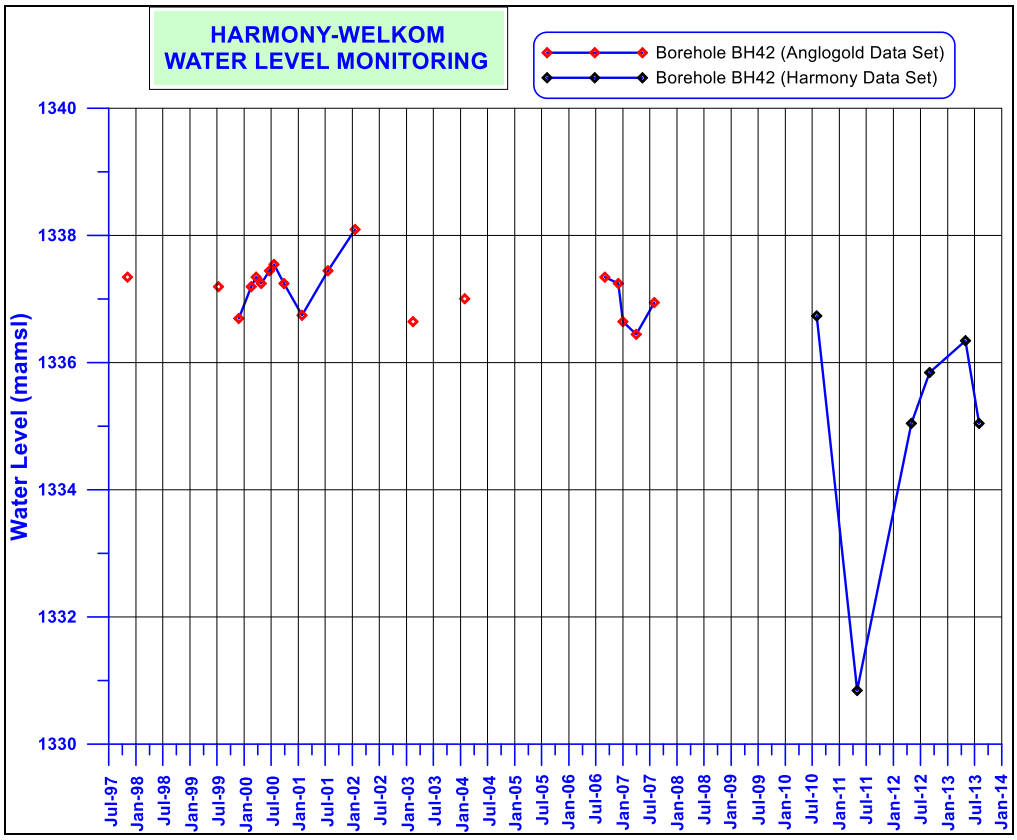

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH37 (Anglogold Data Set)
Borehole BH37 (Harmony Data Set)
Water Level (mamsl)
1388
1386
1384
1382
1380
1378
1376
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04

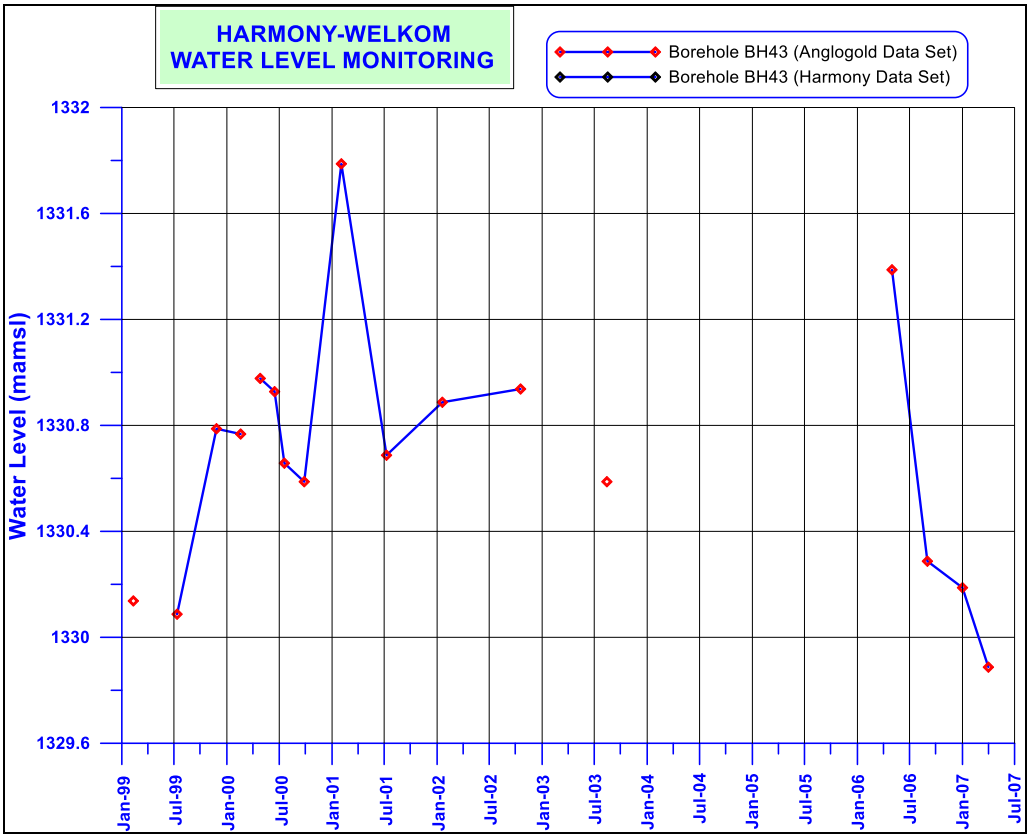

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH38 (Anglogold Data Set)
Borehole BH38 (Harmony Data Set)
Water Level (mamsl)
1379.6
1379.2
1378.8
1378.4
1378
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02

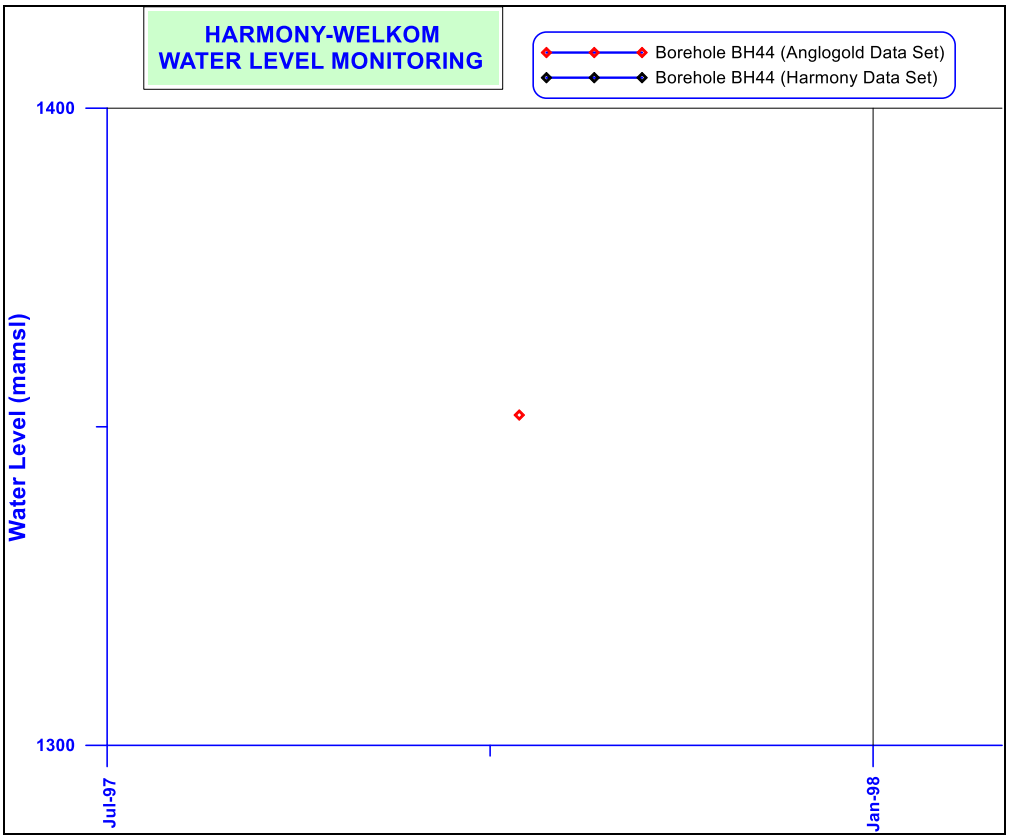

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH39 (Anglogold Data Set)
Borehole BH39 (Harmony Data Set)
Water Level (mamsl)
1382
1381
1380
1379
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11

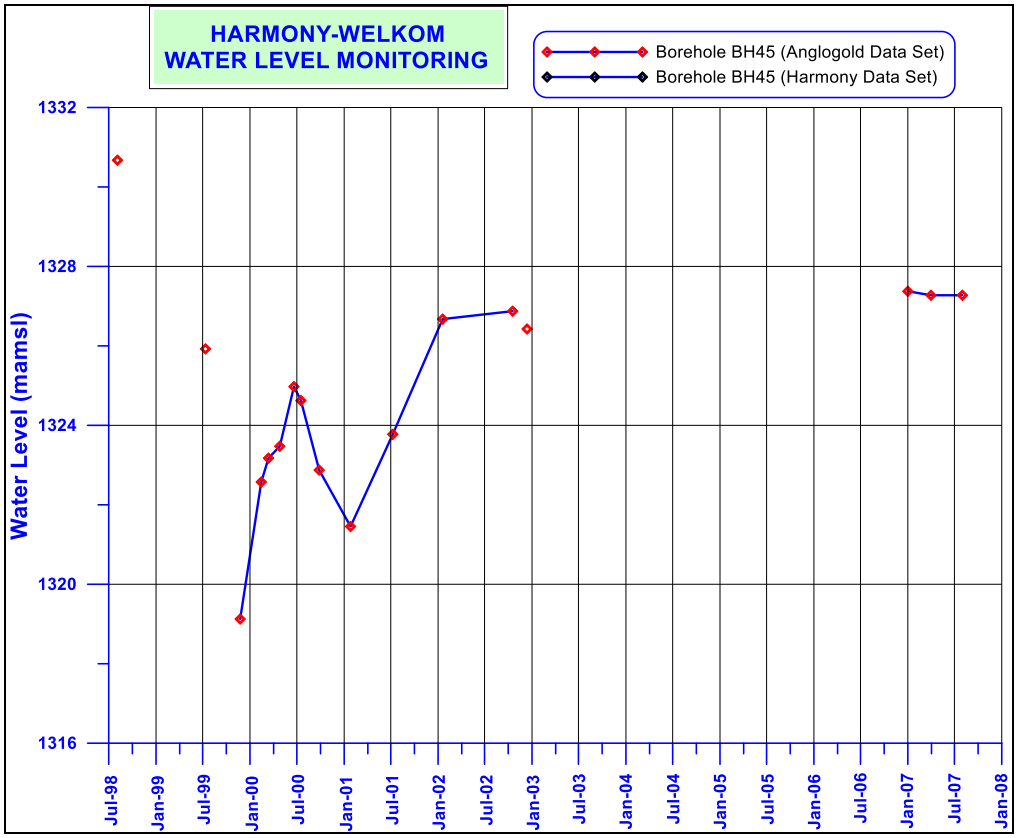

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH40 (Anglogold Data Set)
Borehole BH40 (Harmony Data Set)
Water Level (mamsl)
1332
1331
1330
1329
1328
1327
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11

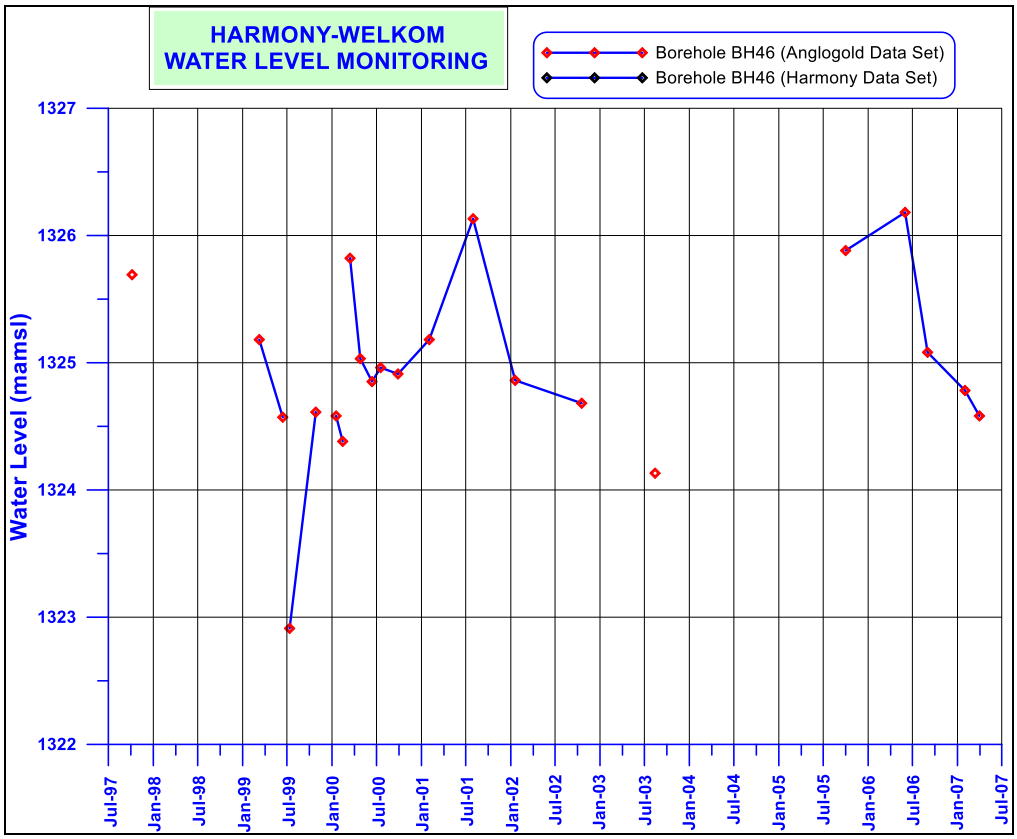

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH41 (Anglogold Data Set)
Borehole BH41 (Harmony Data Set)
Water Level (mamsl)
1332.5
1332
1331.5
1331
1330.5
1330
1329.5
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

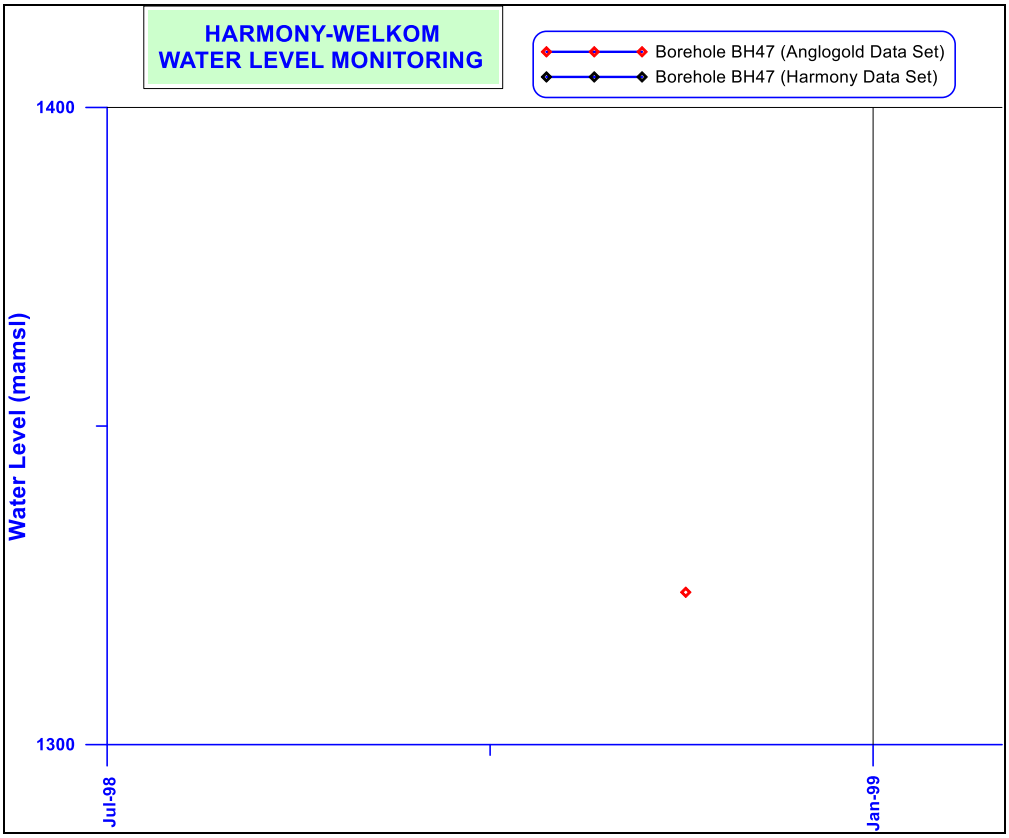

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH42 (Anglogold Data Set)
Borehole BH42 (Harmony Data Set)
Water Level (mamsl)
1340
1338
1336
1334
1332
1330
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

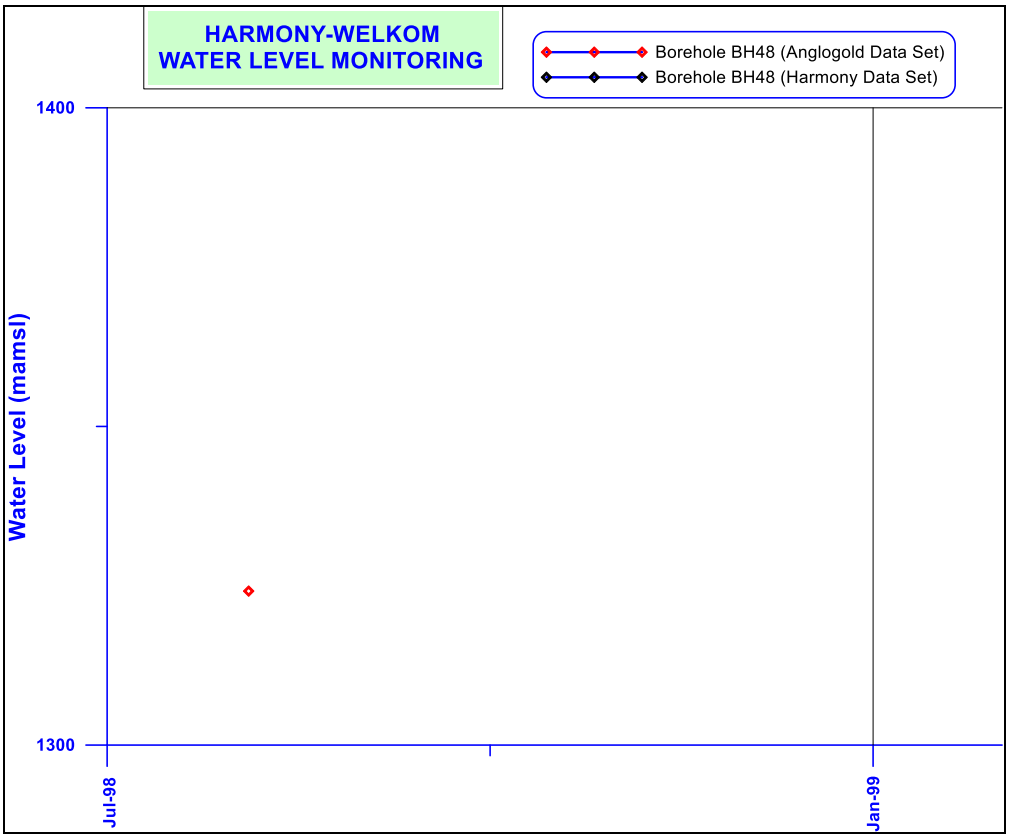

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH43 (Anglogold Data Set)
Borehole BH43 (Harmony Data Set)
Water Level (mamsl)
1332
1331.6
1331.2
1330.8
1330.4
1330
1329.6
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

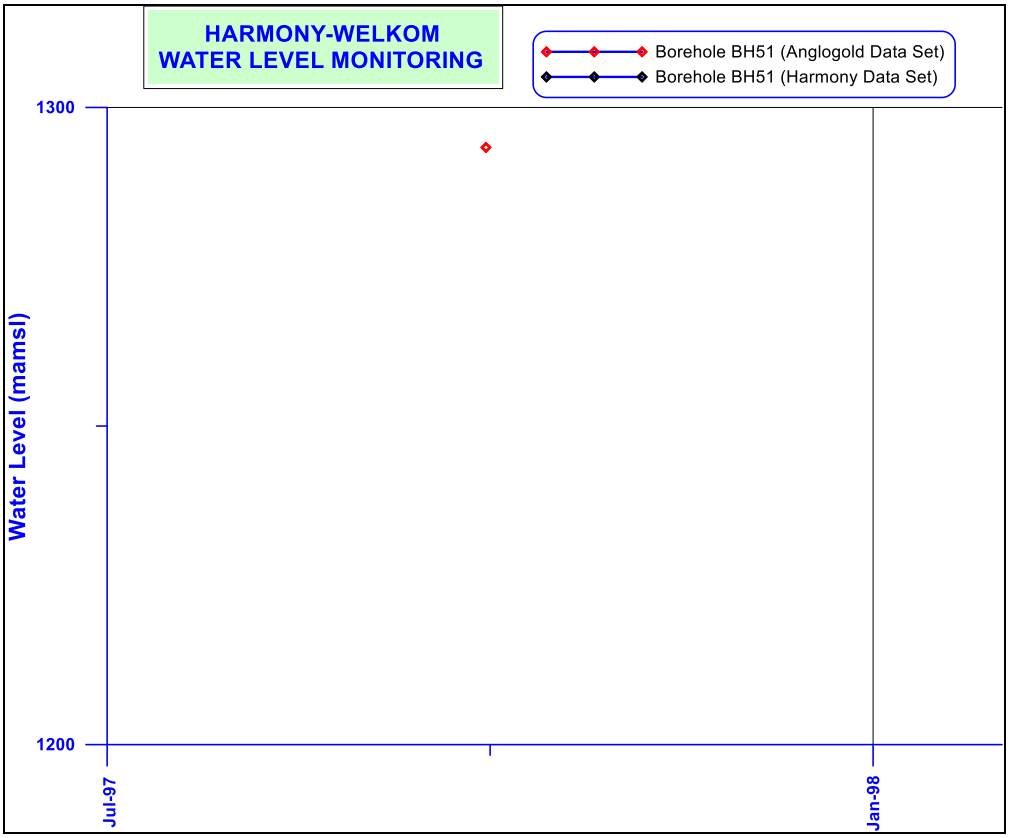

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH44 (Anglogold Data Set)
Borehole BH44 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jul-97
Jan-98

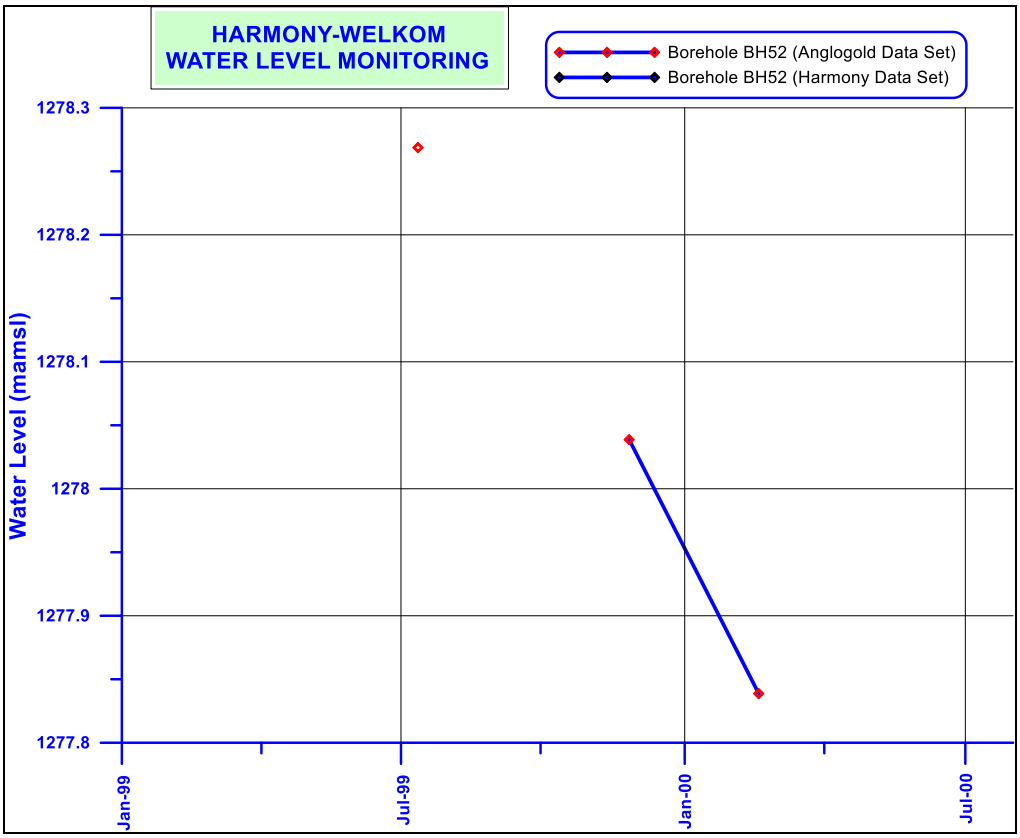

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH45 (Anglogold Data Set)
Borehole BH45 (Harmony Data Set)
Water Level (mamsl)
1332
1328
1324
1320
1316
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08

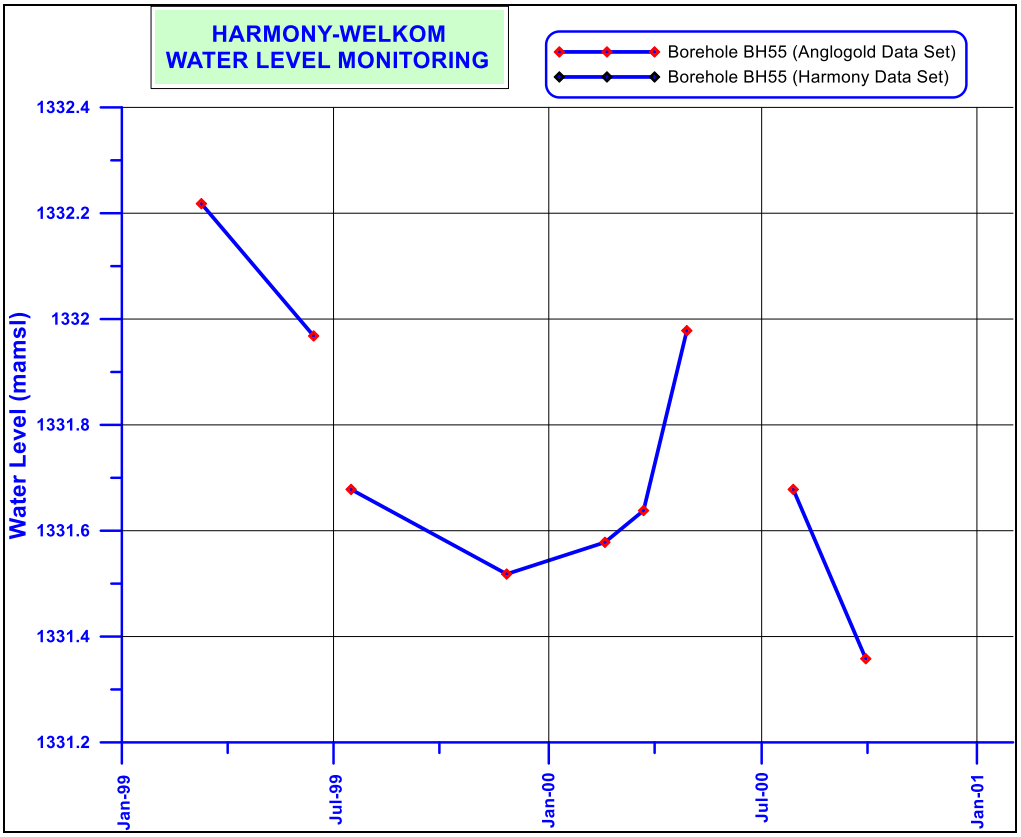

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH46 (Anglogold Data Set)
Borehole BH46 (Harmony Data Set)
Water Level (mamsl)
1327
1326
1325
1324
1323
1322
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

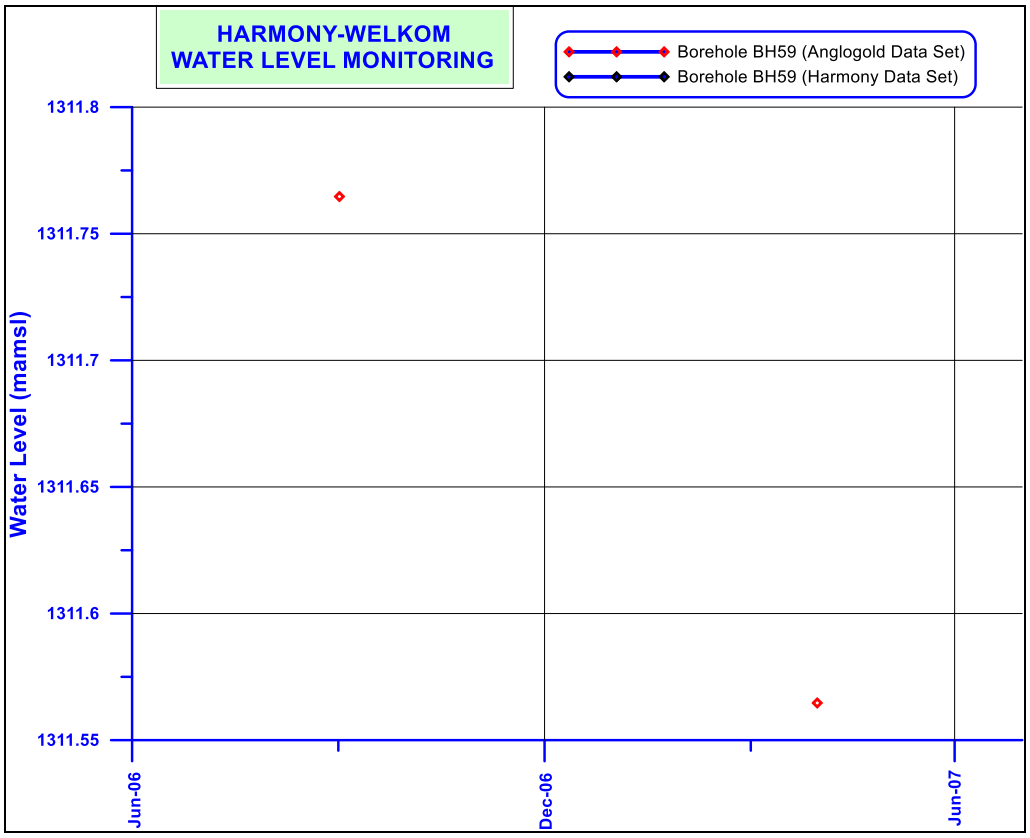

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH47 (Anglogold Data Set)
Borehole BH47 (Harmony Data Set)
1400
1300
Water Level (mamsl)
Jul-98
Jan-99

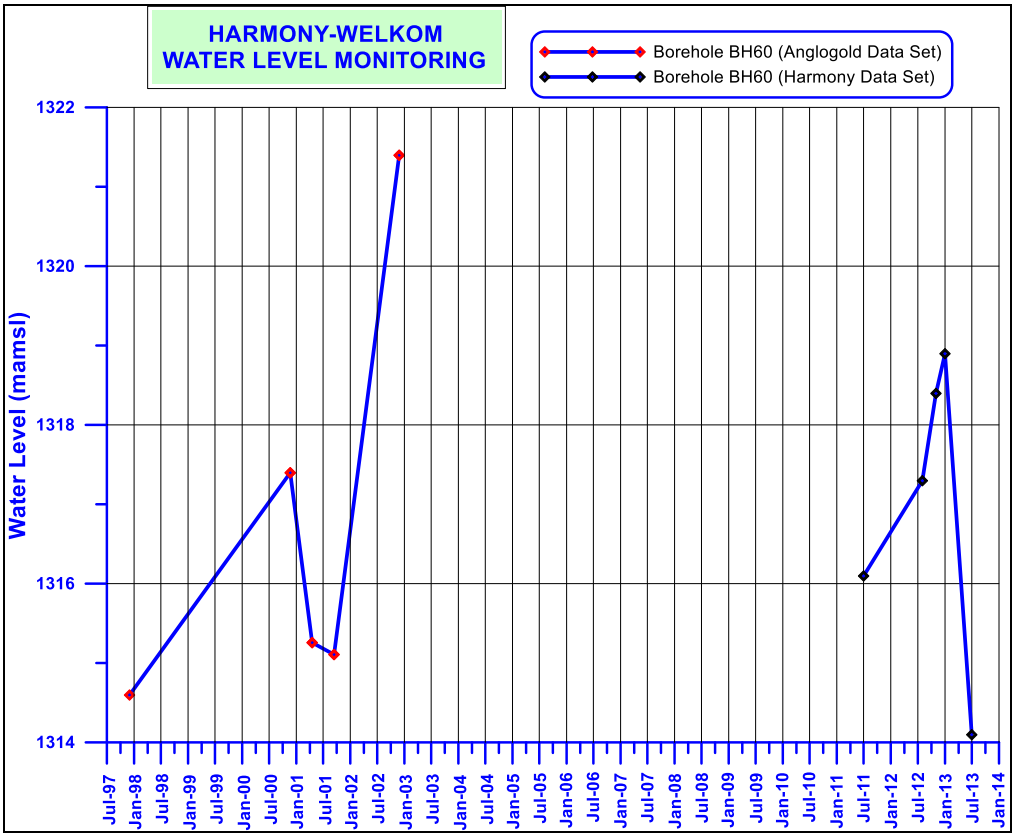

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH48 (Anglogold Data Set)
Borehole BH48 (Harmony Data Set)
1400
1300
Water Level (mamsl)
Jul-98
Jan-99

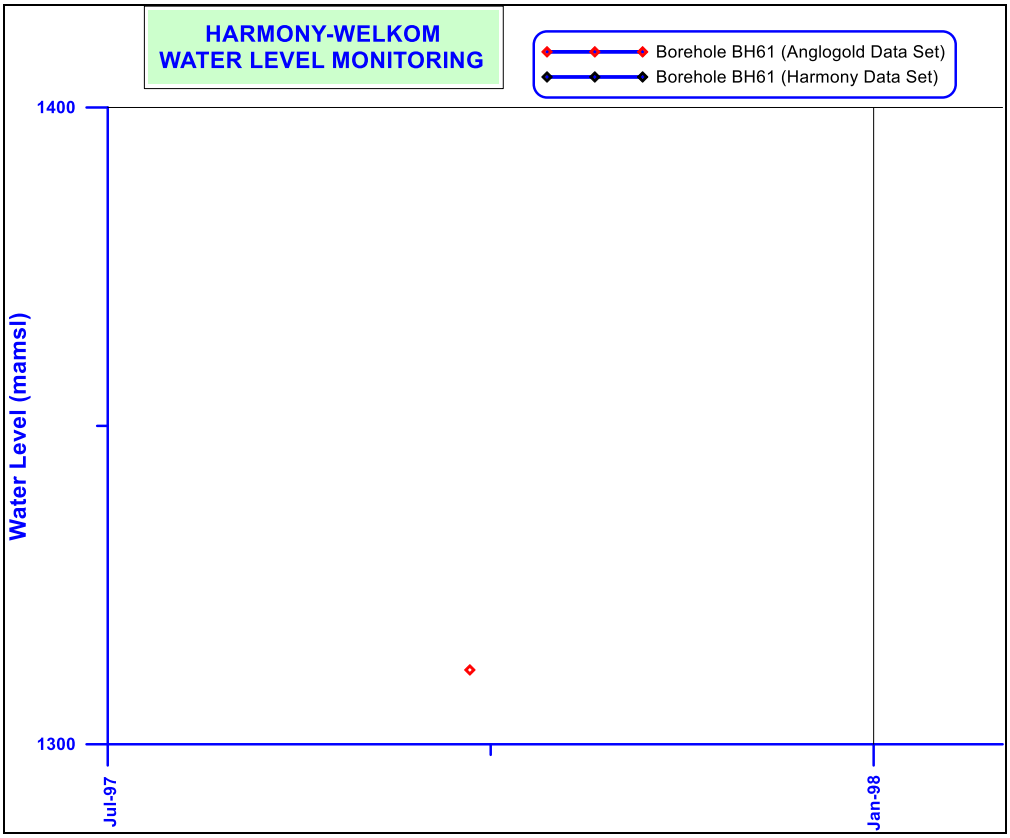

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH51 (Anglogold Data Set)
Borehole BH51 (Harmony Data Set)
Water Level (mamsl)
1300
1200
Jul-97
Jan-98

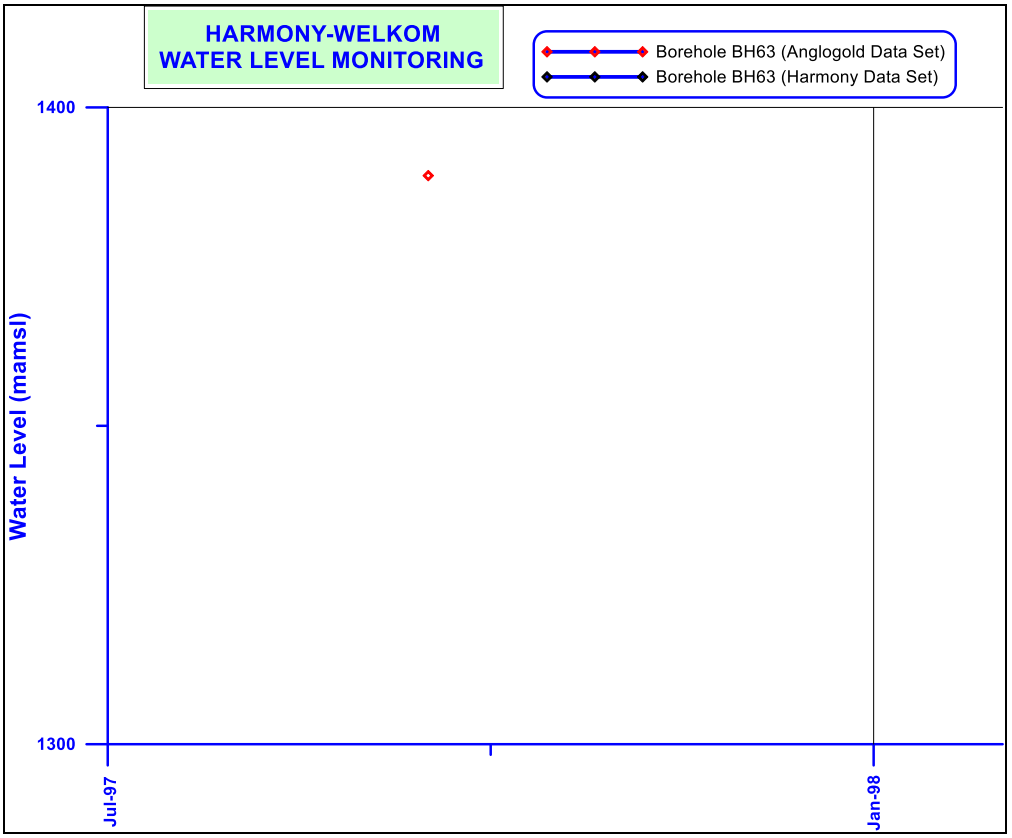

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH52 (Anglogold Data Set)
Borehole BH52 (Harmony Data Set)
Water Level (mamsl)
1278.3
1278.2
1278.1
1278
1277.9
1277.8
Jan-99
Jul-99
Jan-00
Jul-00

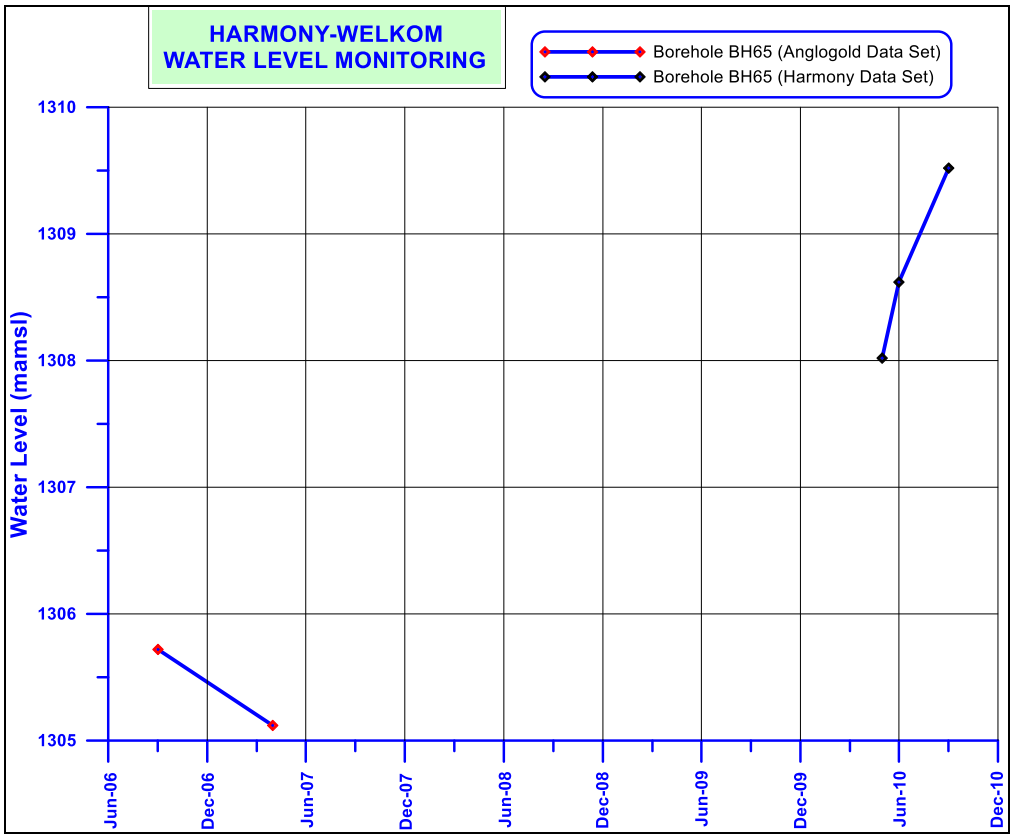

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH55 (Anglogold Data Set)
Borehole BH55 (Harmony Data Set)
Water Level (mamsl)
1332.4
1332.2
1332
1331.8
1331.6
1331.4
1331.2
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01

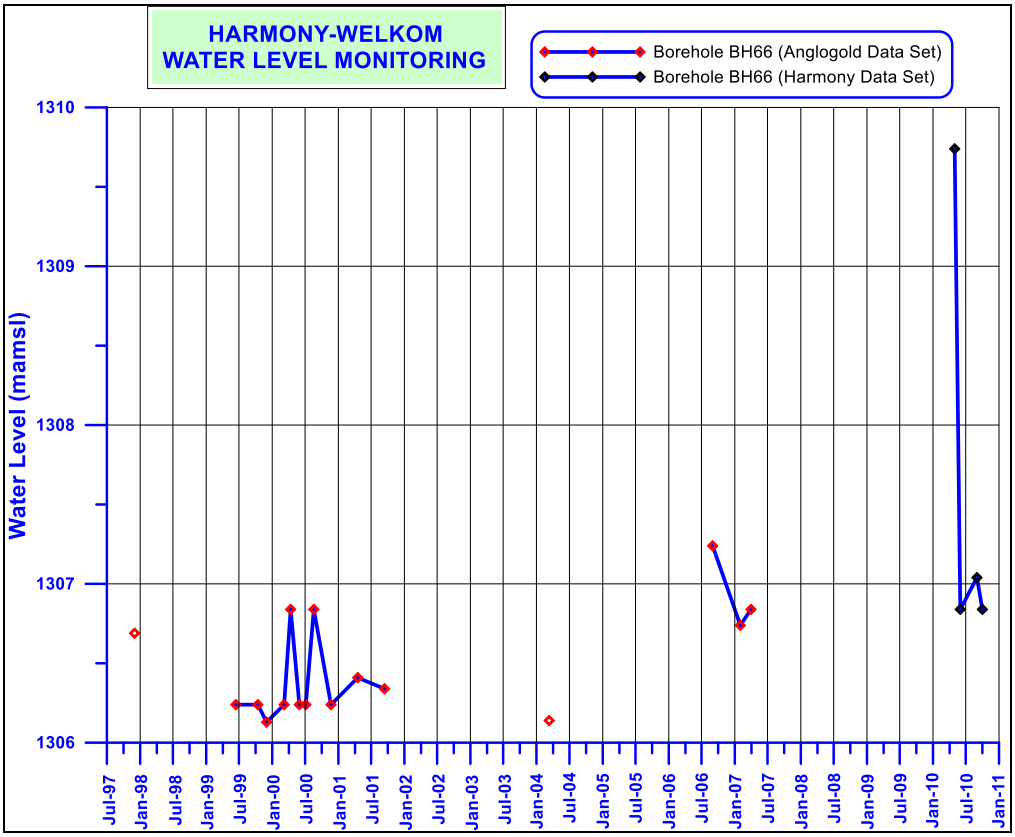

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH59 (Anglogold Data Set)
Borehole BH59 (Harmony Data Set)
Water Level (mamsl)
1311.8
1311.75
1311.7
1311.65
1311.6
1311.55
Jun-06
Dec-06
Jun-07

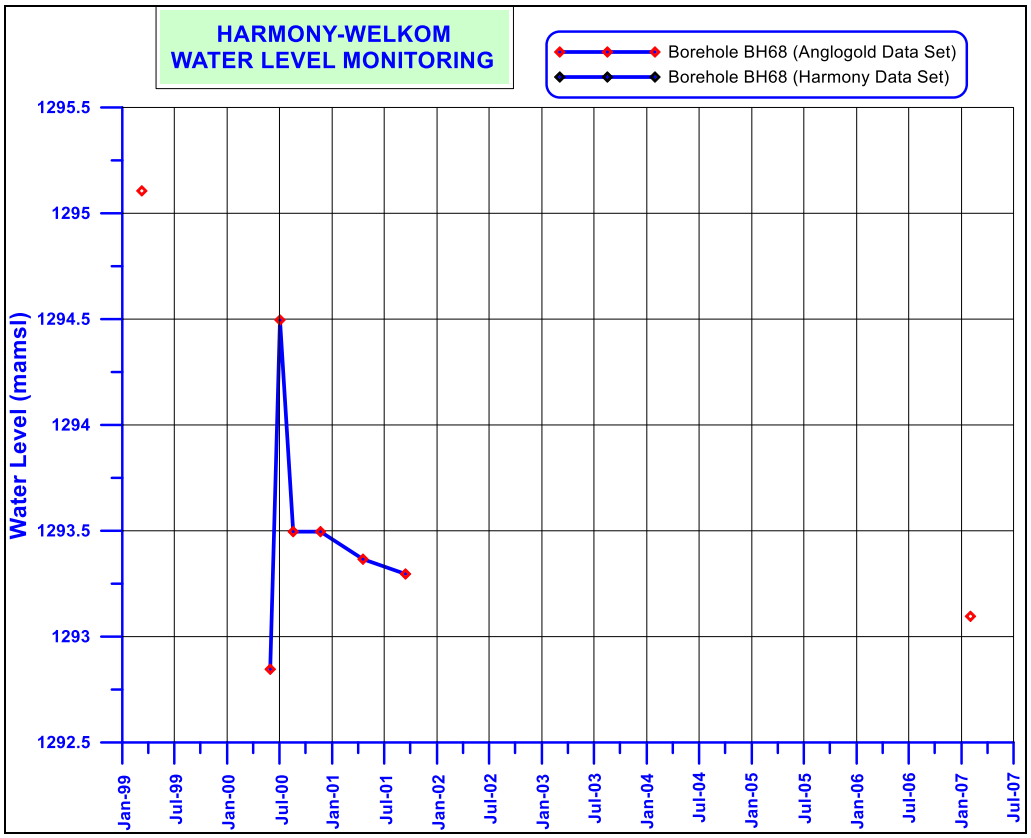

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH60 (Anglogold Data Set)
Borehole BH60 (Harmony Data Set)
Water Level (mamsl)
1322
1320
1318
1316
1314
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14

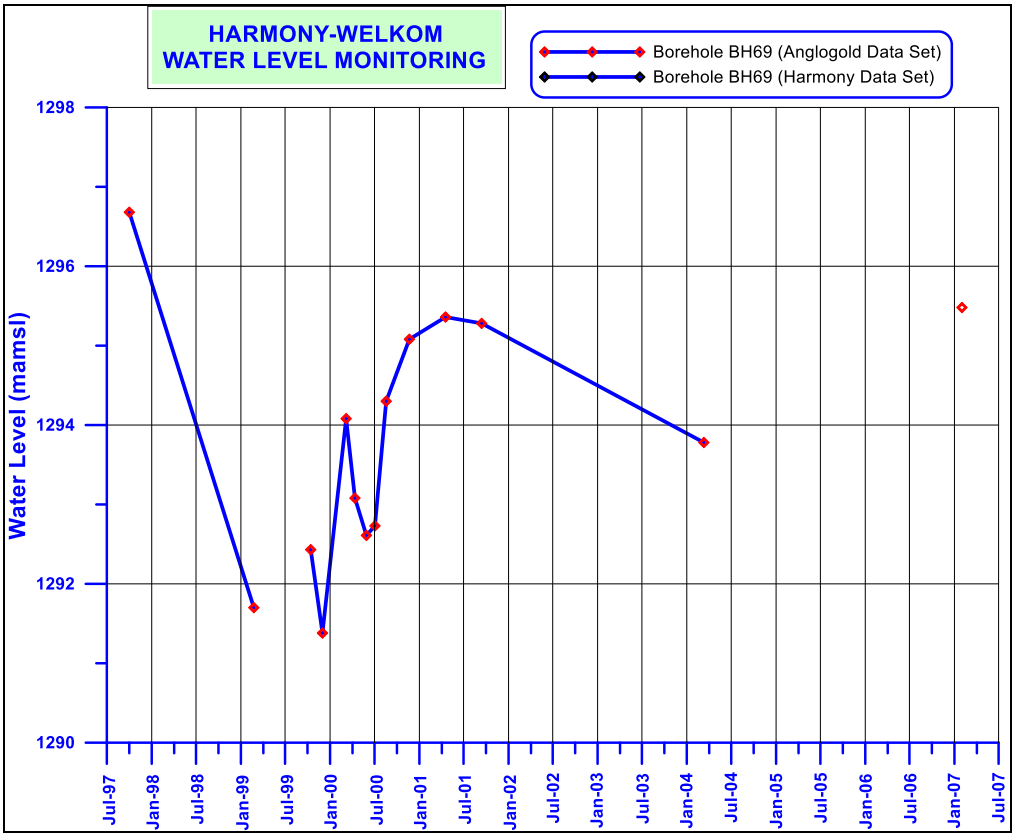

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH61 (Anglogold Data Set)
Borehole BH61 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jul-97
Jan-98

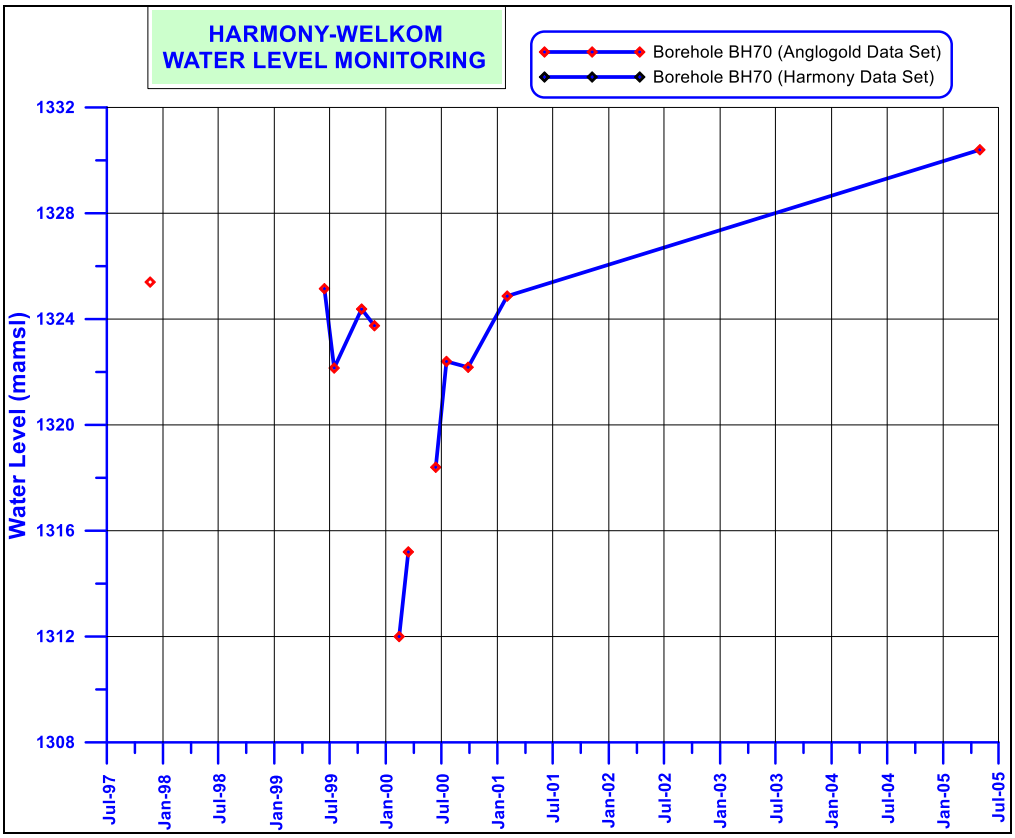

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH63 (Anglogold Data Set)
Borehole BH63 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Jul-97
Jan-98

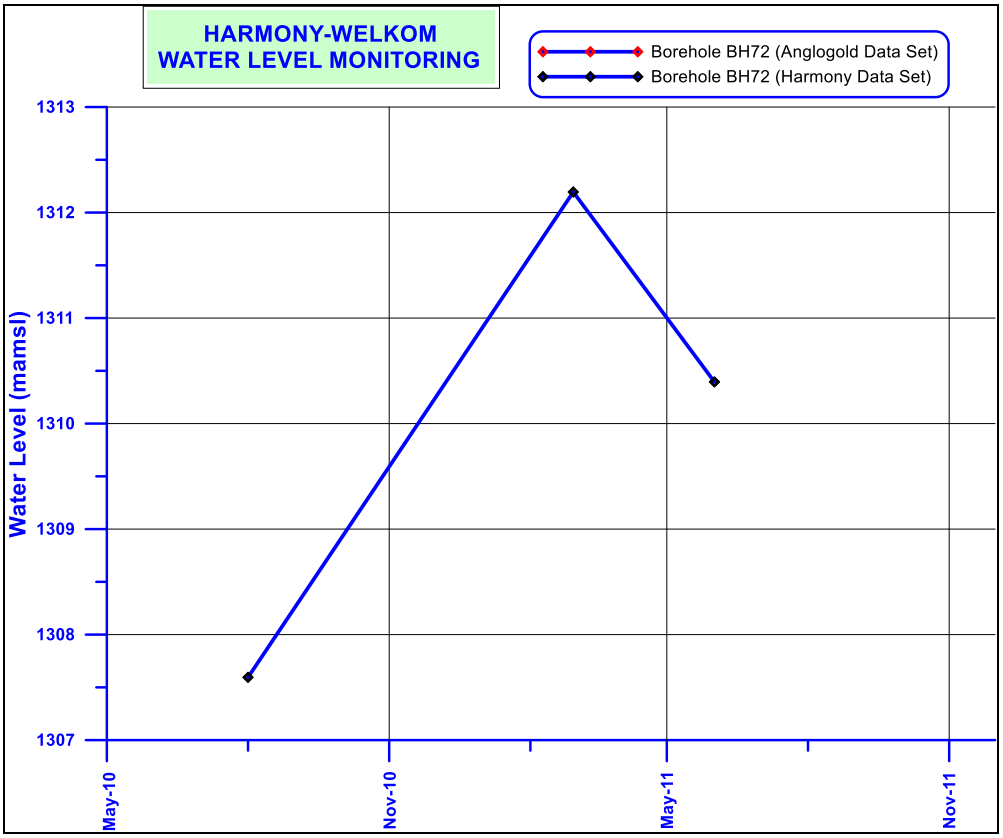

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH65 (Anglogold Data Set)
Borehole BH65 (Harmony Data Set)
Water Level (mamsl)
1310
1309
1308
1307
1306
1305
Jun-06
Dec-06
Jun-07
Dec-07
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10

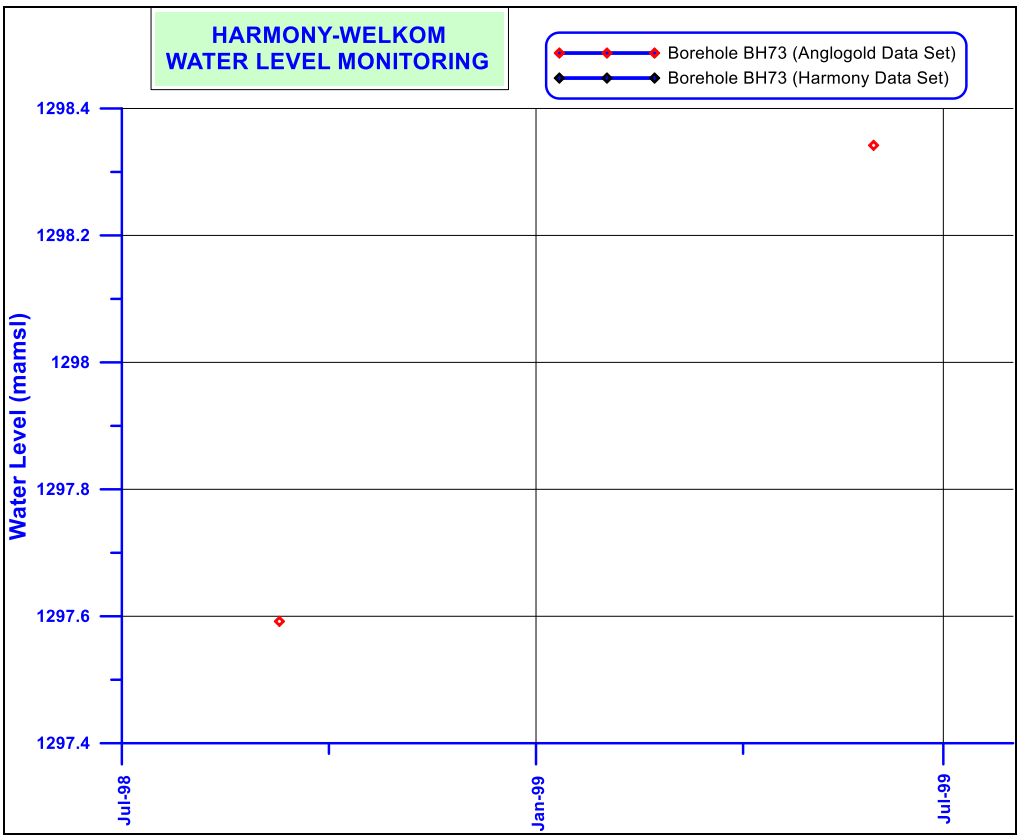

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH66 (Anglogold Data Set)
Borehole BH66 (Harmony Data Set)
Water Level (mamsl)
1310
1309
1308
1307
1306
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09
Jul-09
Jan-10
Jul-10
Jan-11

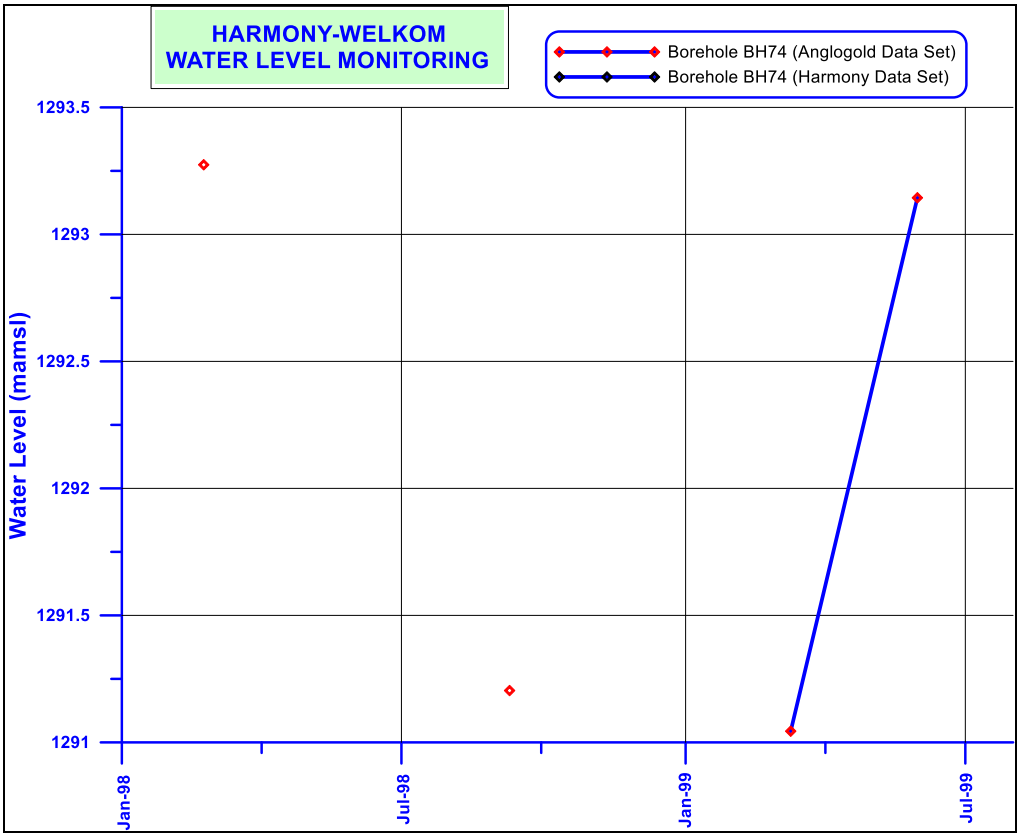

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH68 (Anglogold Data Set)
Borehole BH68 (Harmony Data Set)
Water Level (mamsl)
1295.5
1295
1294.5
1294
1293.5
1293
1292.5
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

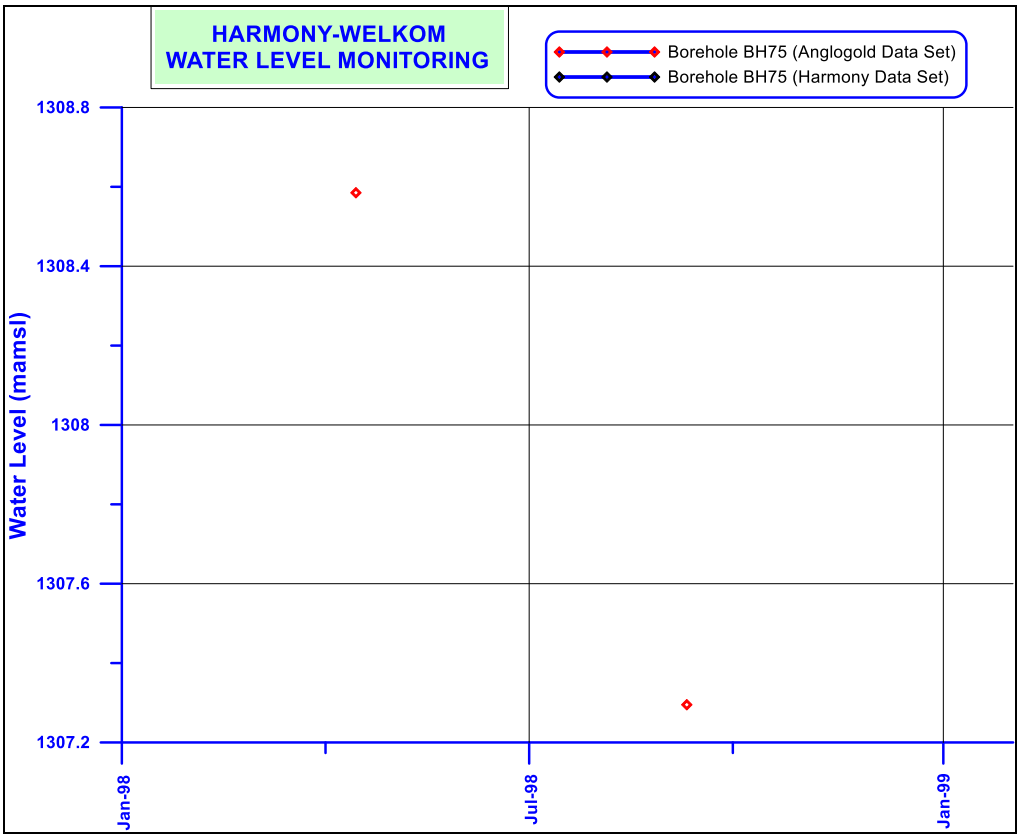

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH69 (Anglogold Data Set)
Borehole BH69 (Harmony Data Set)
Water Level (mamsl)
1298
1296
1294
1292
1290
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07

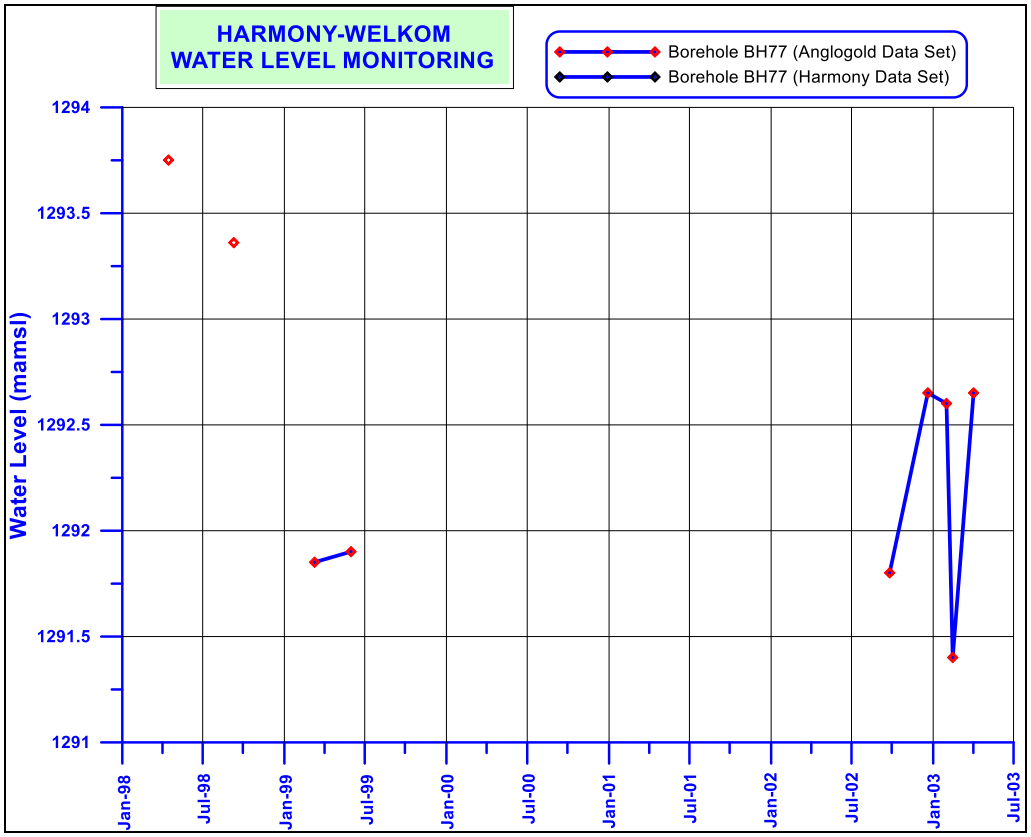

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH70 (Anglogold Data Set)
Borehole BH70 (Harmony Data Set)
Water Level (mamsl)
1332
1328
1324
1320
1316
1312
1308
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05

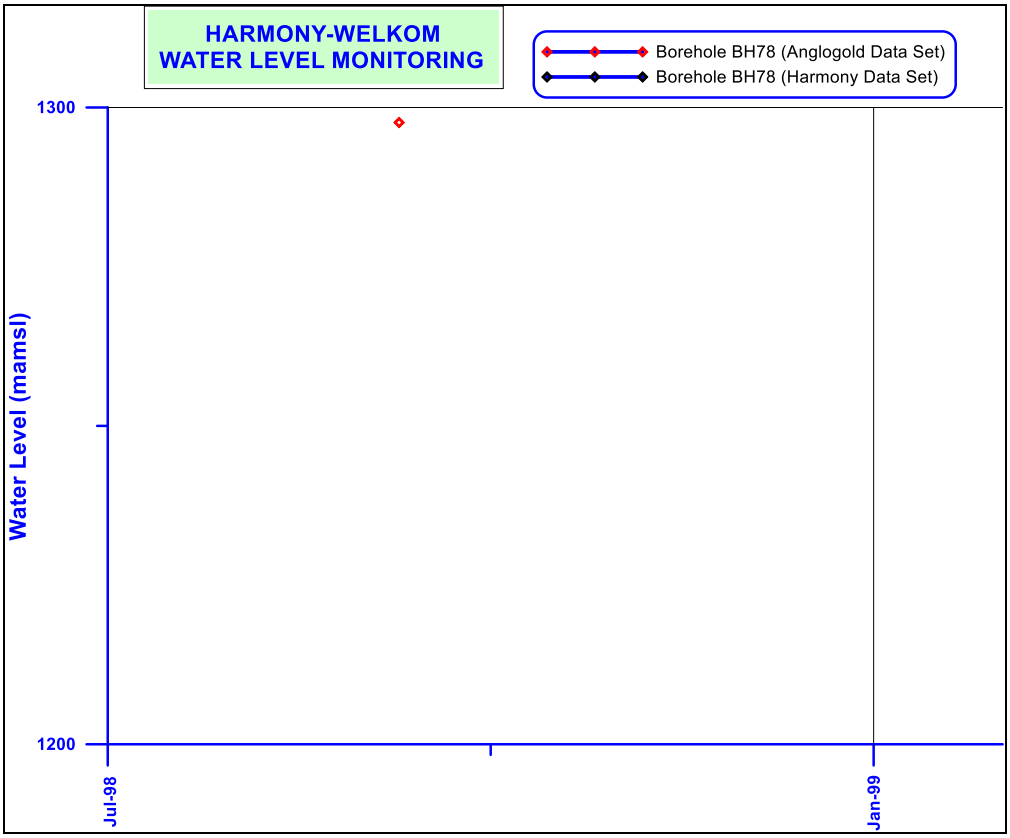

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH72 (Anglogold Data Set)
Borehole BH72 (Harmony Data Set)
Water Level (mamsl)
1313
1312
1311
1310
1309
1308
1307
May-10
Nov-10
May-11
Nov-11

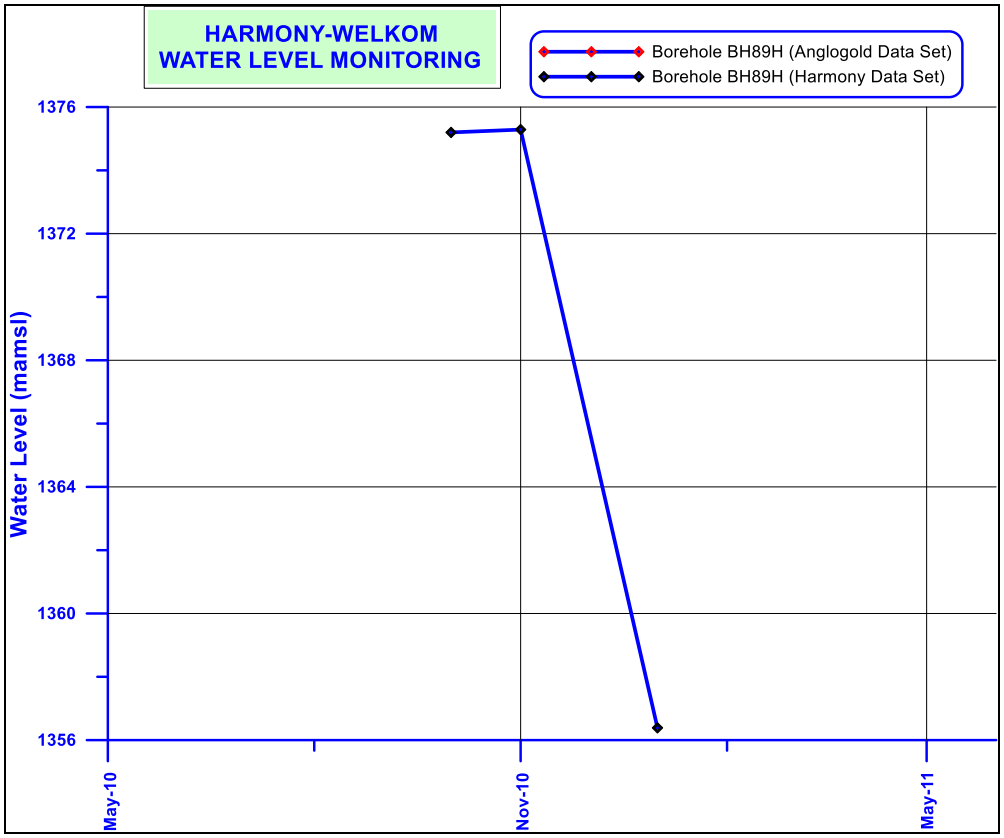

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH73 (Anglogold Data Set)
Borehole BH73 (Harmony Data Set)
Water Level (mamsl)
1298.4
1298.2
1298
1297.8
1297.6
1297.4
Jul-98
Jan-99
Jul-99

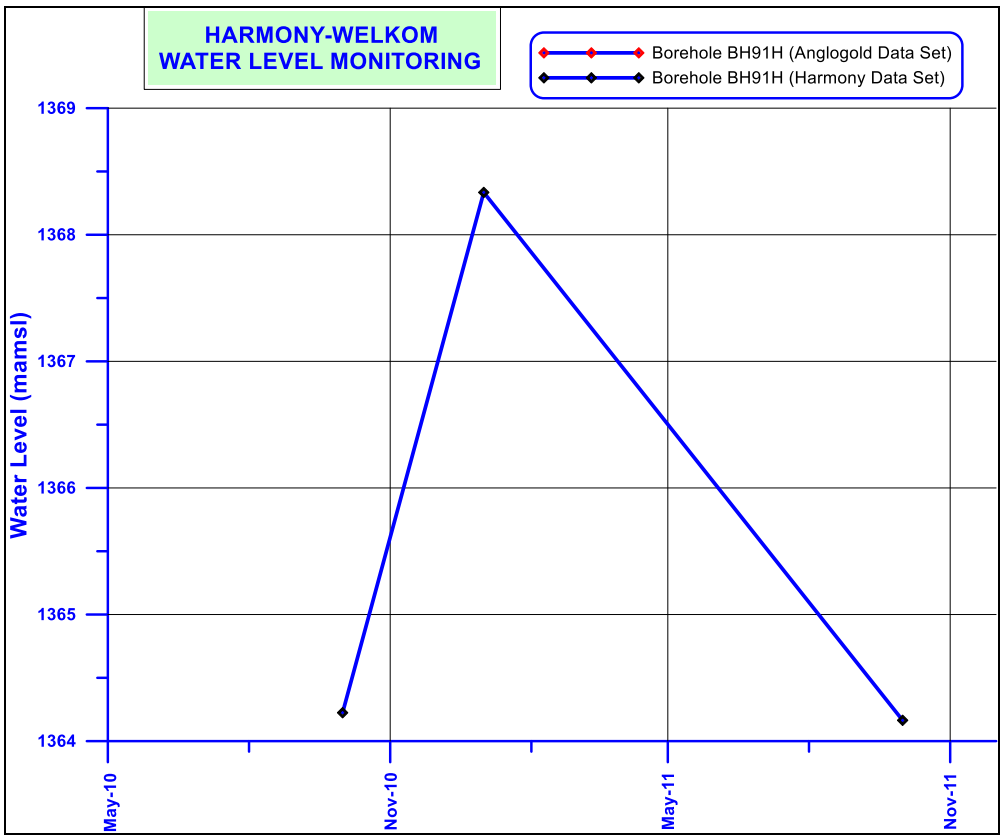

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH74 (Anglogold Data Set)
Borehole BH74 (Harmony Data Set)
Water Level (mamsl)
1293.5
1293
1292.5
1292
1291.5
1291
Jan-98
Jul-98
Jan-99
Jul-99

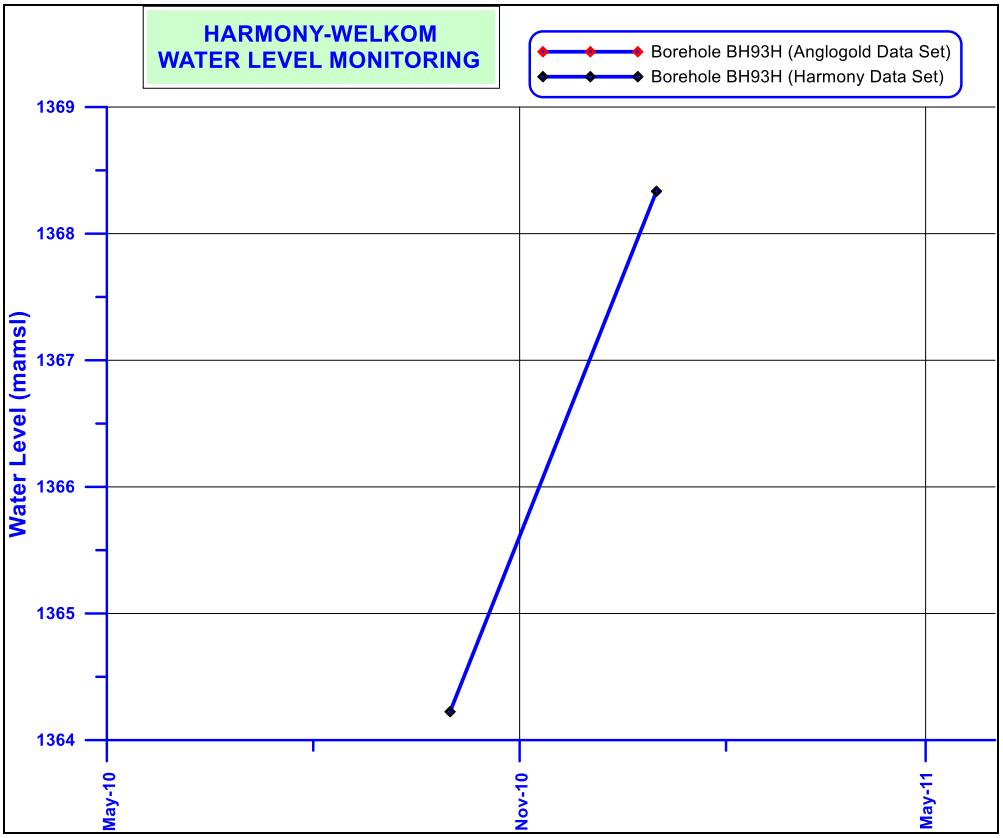

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH75 (Anglogold Data Set)
Borehole BH75 (Harmony Data Set)
Water Level (mamsl)
1308.8
1308.4
1308
1307.6
1307.2
Jan-98
Jul-98
Jan-99

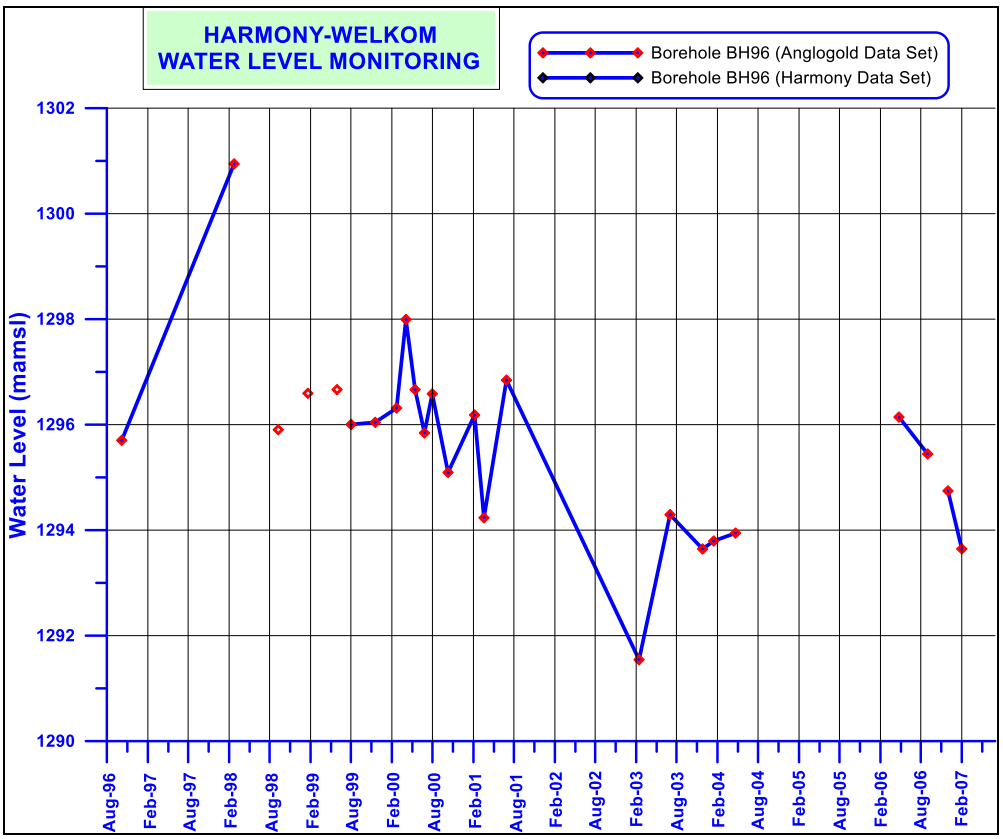

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH77 (Anglogold Data Set)
Borehole BH77 (Harmony Data Set)
Water Level (mamsl)
1294
1293.5
1293
1292.5
1292
1291.5
1291
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03

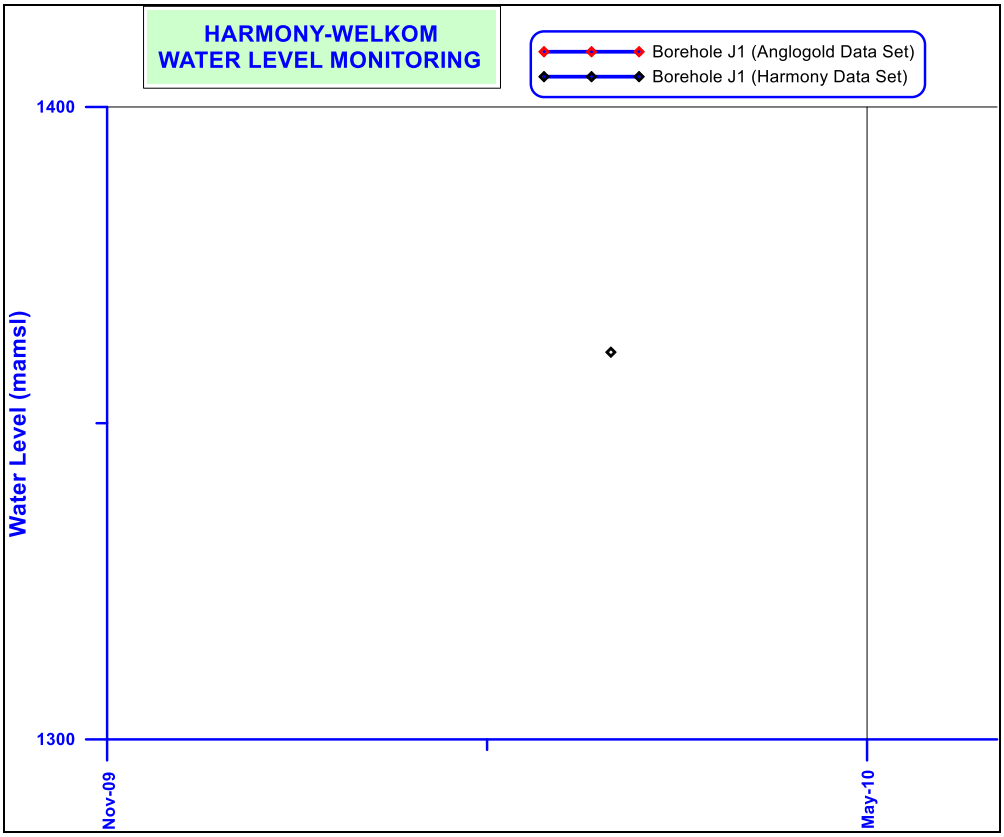

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH78 (Anglogold Data Set)
Borehole BH78 (Harmony Data Set)
Water Level (mamsl)
1300
1200
Jul-98
Jan-99

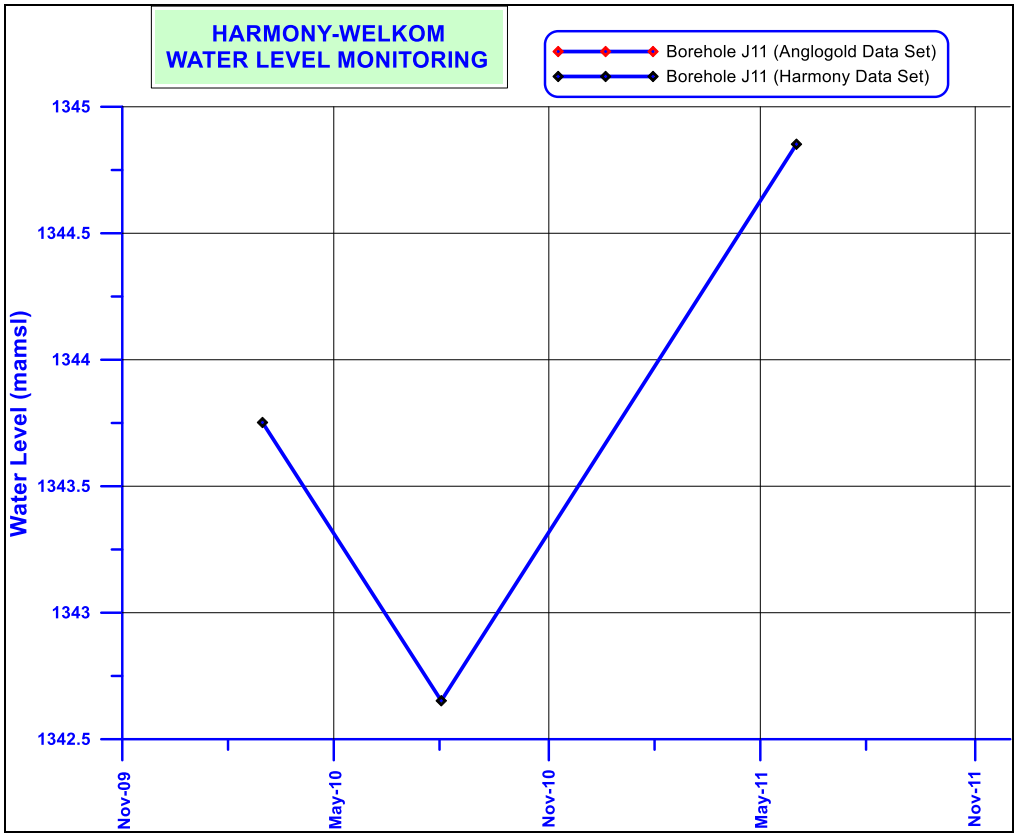

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH89H (Anglogold Data Set)
Borehole BH89H (Harmony Data Set)
Water Level (mamsl)
1376
1372
1368
1364
1360
1356
May-10
Nov-10
May-11

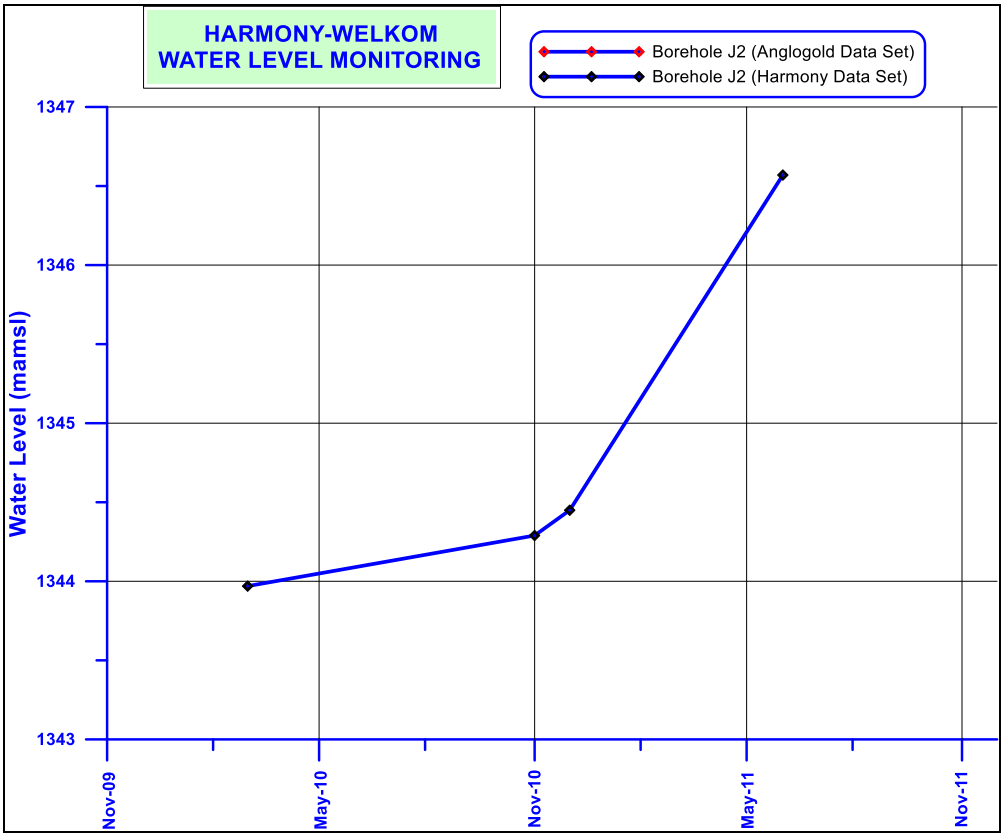

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH91H (Anglogold Data Set)
Borehole BH91H (Harmony Data Set)
Water Level (mamsl)
1369
1368
1367
1366
1365
1364
May-10
Nov-10
May-11
Nov-11

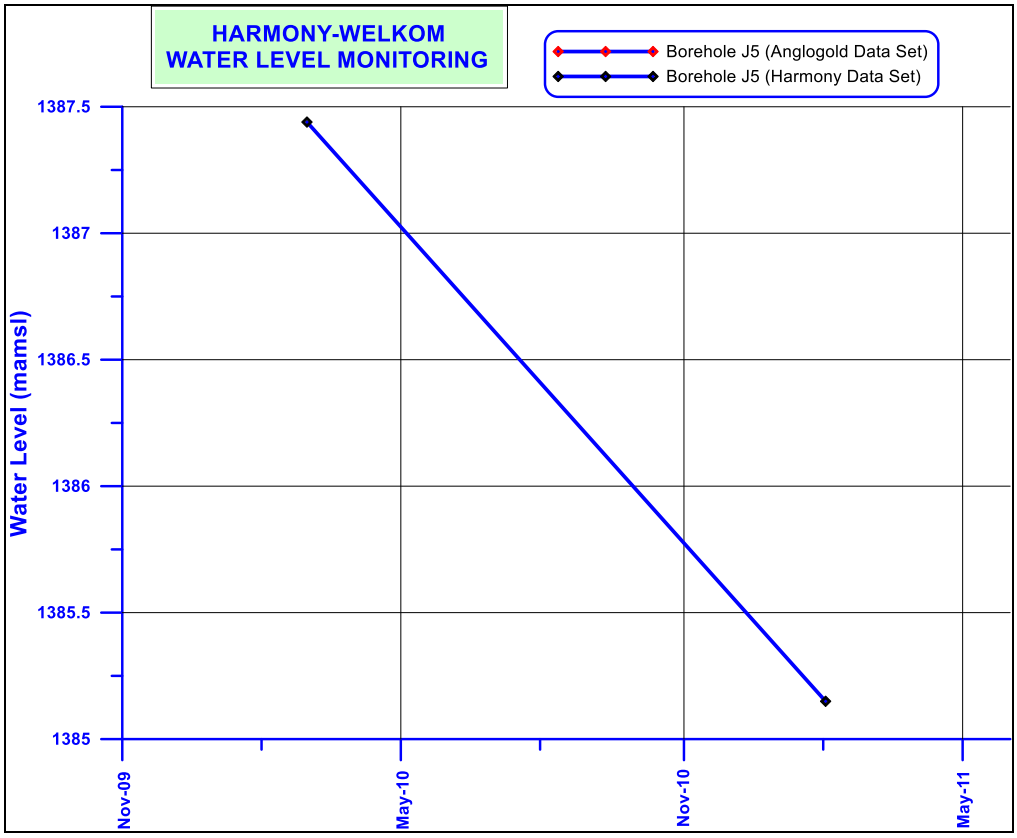

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH93H (Anglogold Data Set)
Borehole BH93H (Harmony Data Set)
Water Level (mamsl)
1369
1368
1367
1366
1365
1364
May-10
Nov-10
May-11

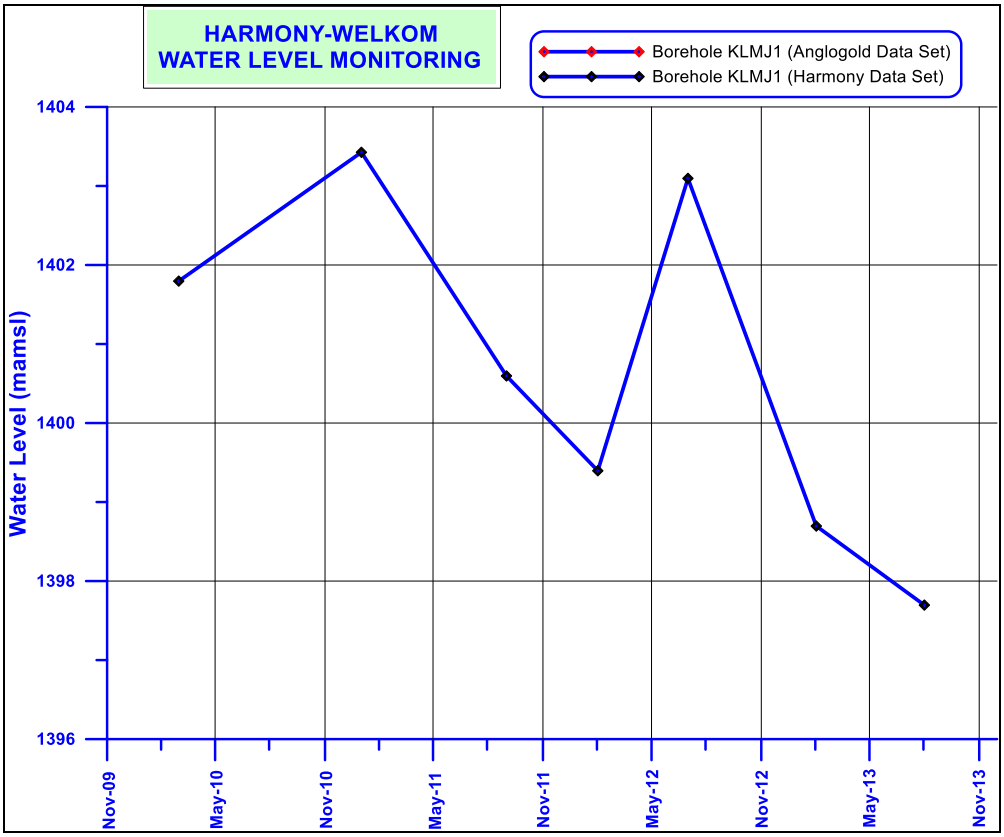

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole BH96 (Anglogold Data Set)
Borehole BH96 (Harmony Data Set)
Water Level (mamsl)
1302
1300
1298
1296
1294
1292
1290
Aug-96
Feb-97
Aug-97
Feb-98
Aug-98
Feb-99
Aug-99
Feb-00
Aug-00
Feb-01
Aug-01
Feb-02
Aug-02
Feb-03
Aug-03
Feb-04
Aug-04
Feb-05
Aug-05
Feb-06
Aug-06
Feb-07

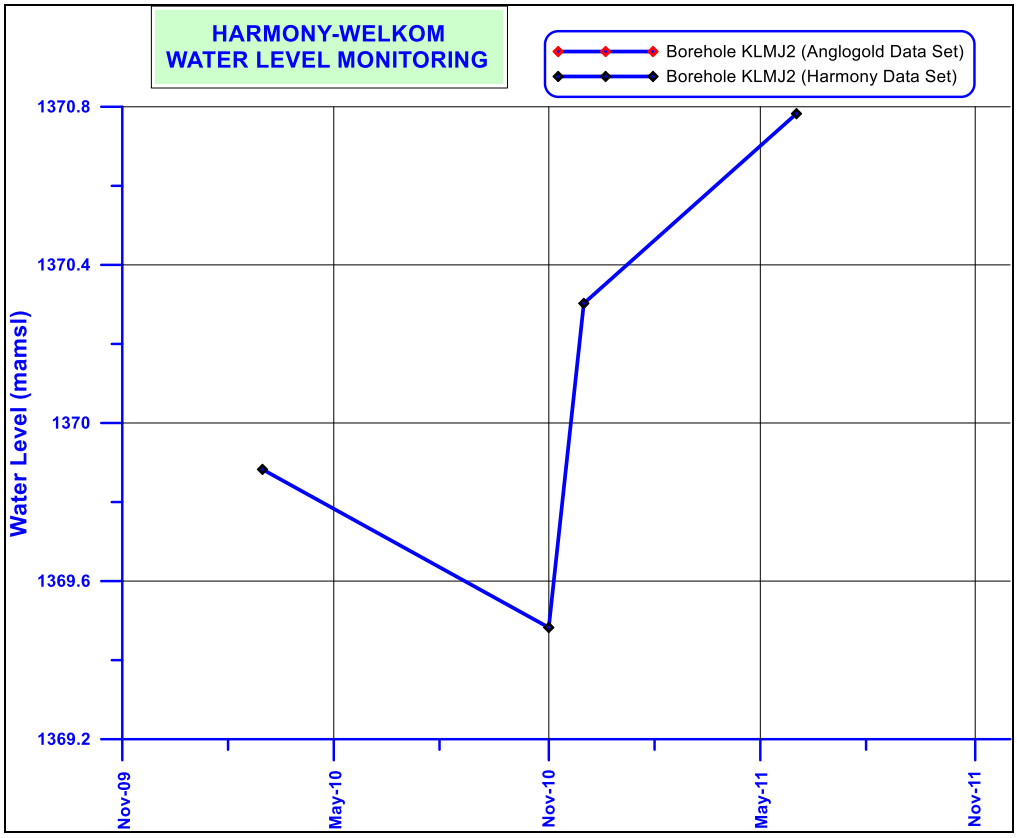

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole J1 (Anglogold Data Set)
Borehole J1 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Nov-09
May-10

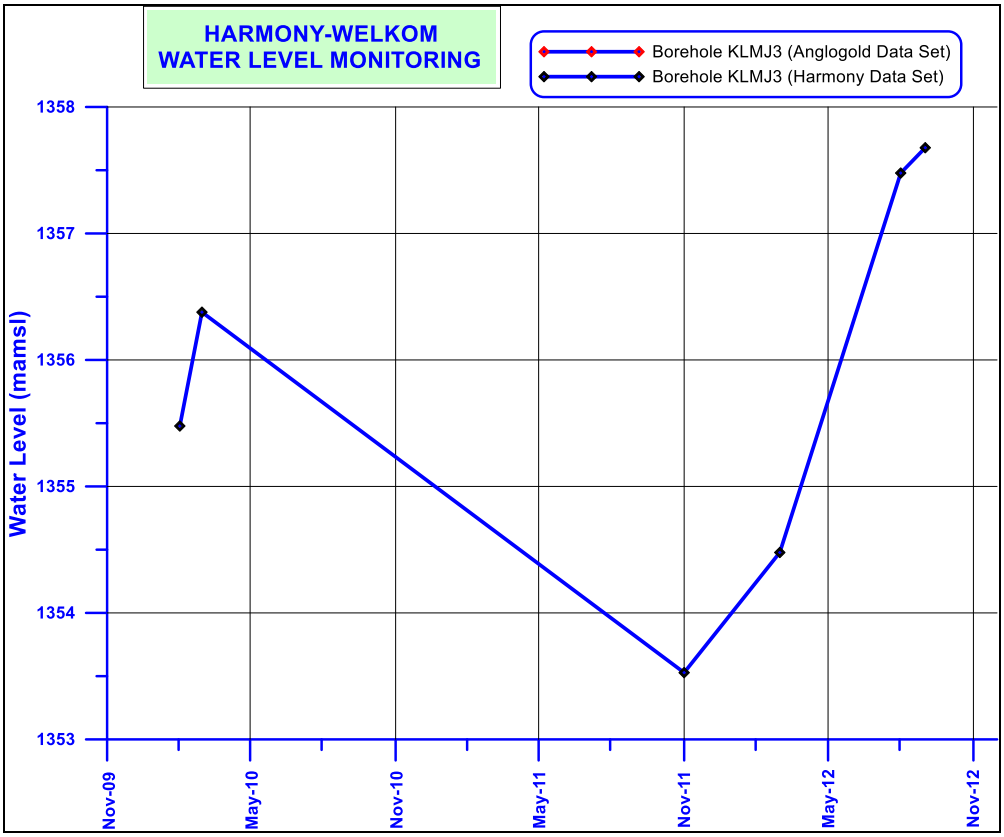

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole J11 (Anglogold Data Set)
Borehole J11 (Harmony Data Set)
Water Level (mamsl)
1345
1344.5
1344
1343.5
1343
1342.5
Nov-09
May-10
Nov-10
May-11
Nov-11

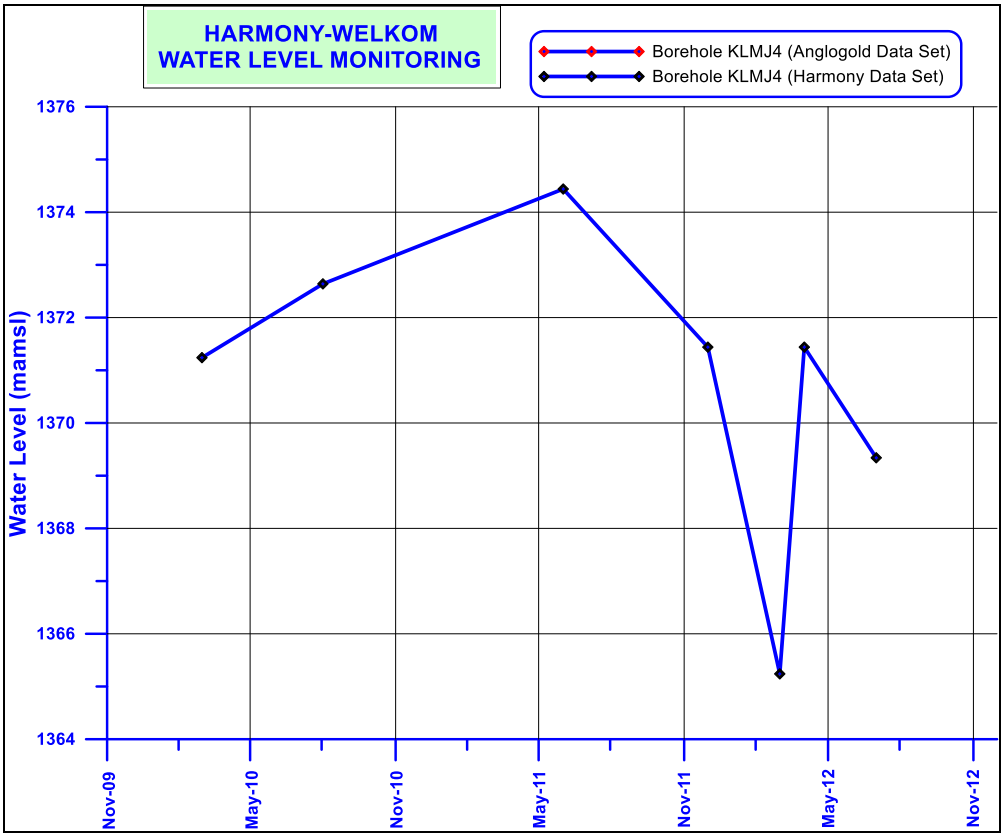

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole J2 (Anglogold Data Set)
Borehole J2 (Harmony Data Set)
Water Level (mamsl)
1347
1346
1345
1344
1343
Nov-09
May-10
Nov-10
May-11
Nov-11

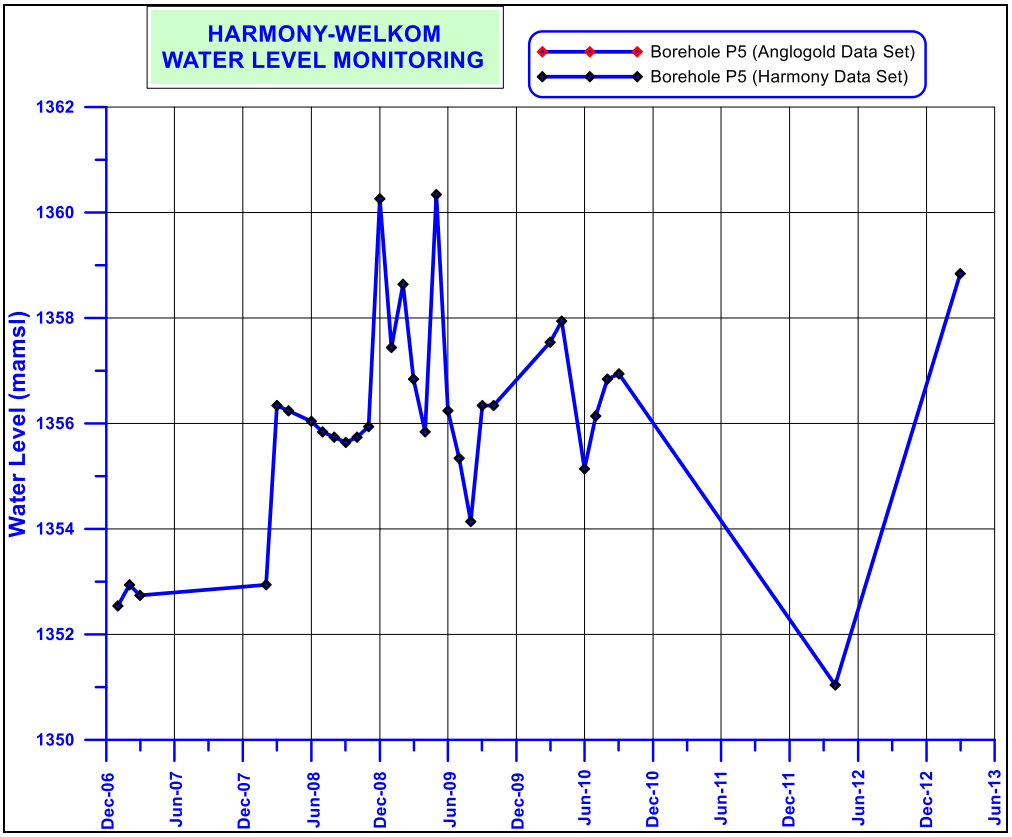

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole J5 (Anglogold Data Set)
Borehole J5 (Harmony Data Set)
Water Level (mamsl)
1387.5
1387
1386.5
1386
1385.5
1385
Nov-09
May-10
Nov-10
May-11

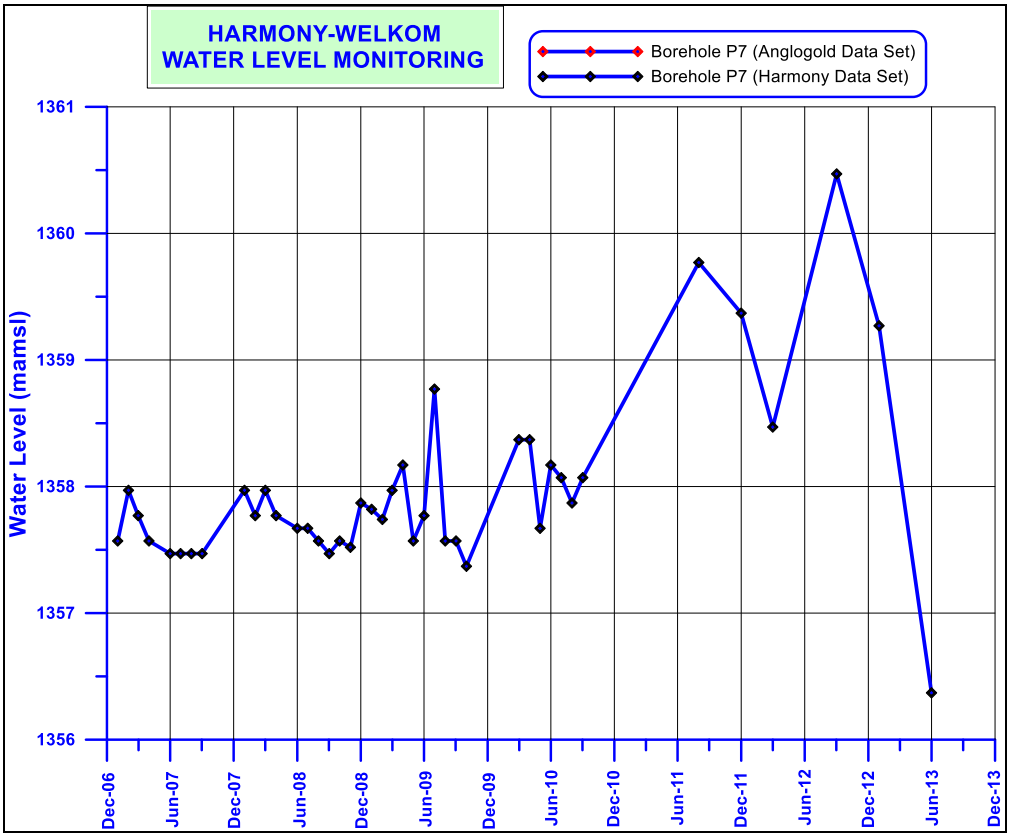

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole KLMJ1 (Anglogold Data Set)
Borehole KLMJ1 (Harmony Data Set)
Water Level (mamsl)
1404
1402
1400
1398
1396
Nov-09
May-10
Nov-10
May-11
Nov-11
May-12
Nov-12
May-13
Nov-13

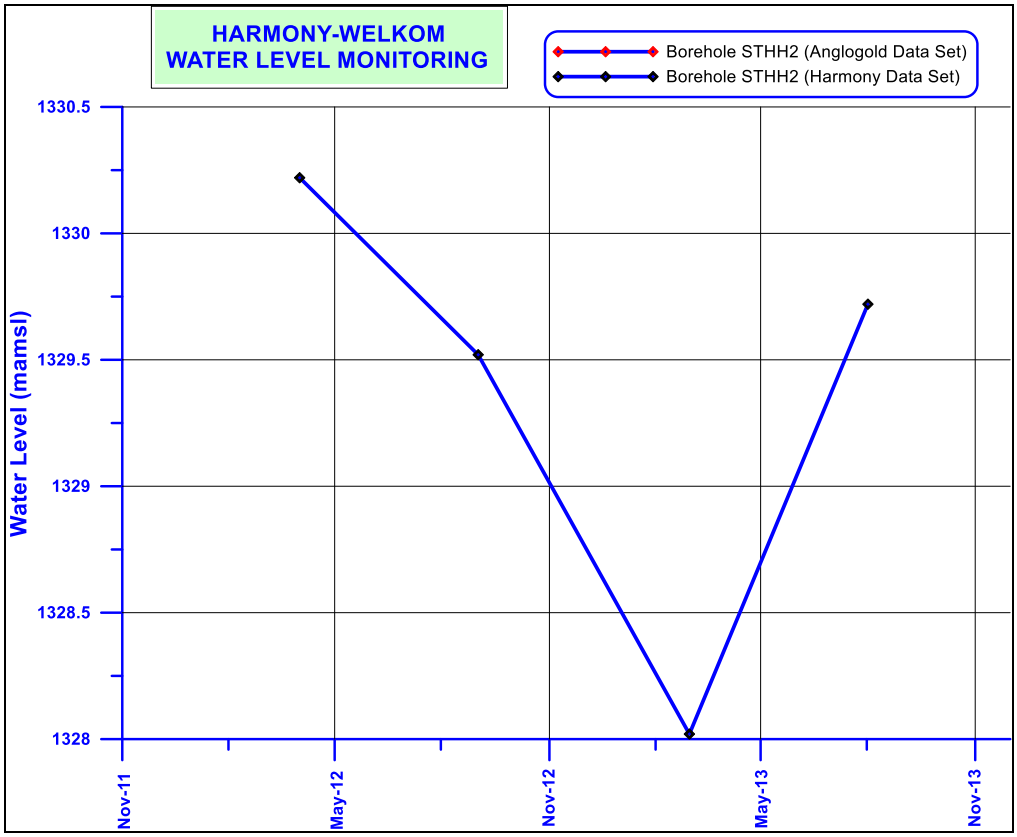

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole KLMJ2 (Anglogold Data Set)
Borehole KLMJ2 (Harmony Data Set)
Water Level (mamsl)
1370.8
1370.4
1370
1369.6
1369.2
Nov-09
May-10
Nov-10
May-11
Nov-11

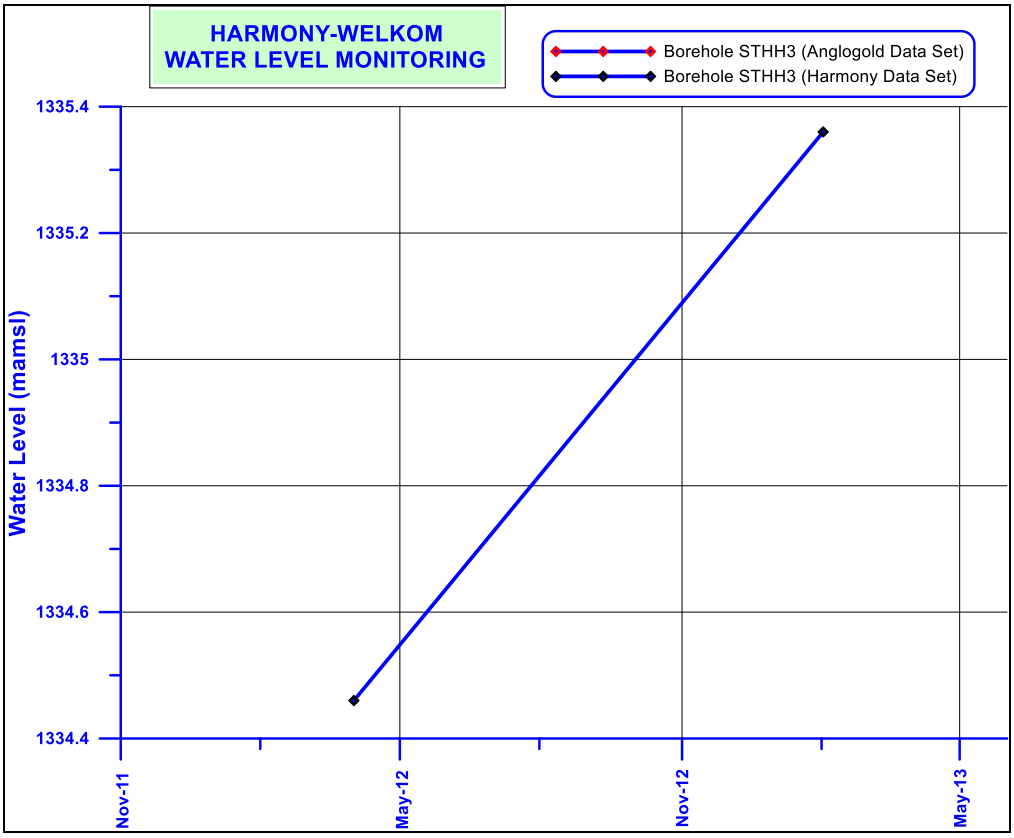

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole KLMJ3 (Anglogold Data Set)
Borehole KLMJ3 (Harmony Data Set)
Water Level (mamsl)
1358
1357
1356
1355
1354
1353
Nov-09
May-10
Nov-10
May-11
Nov-11
May-12
Nov-12

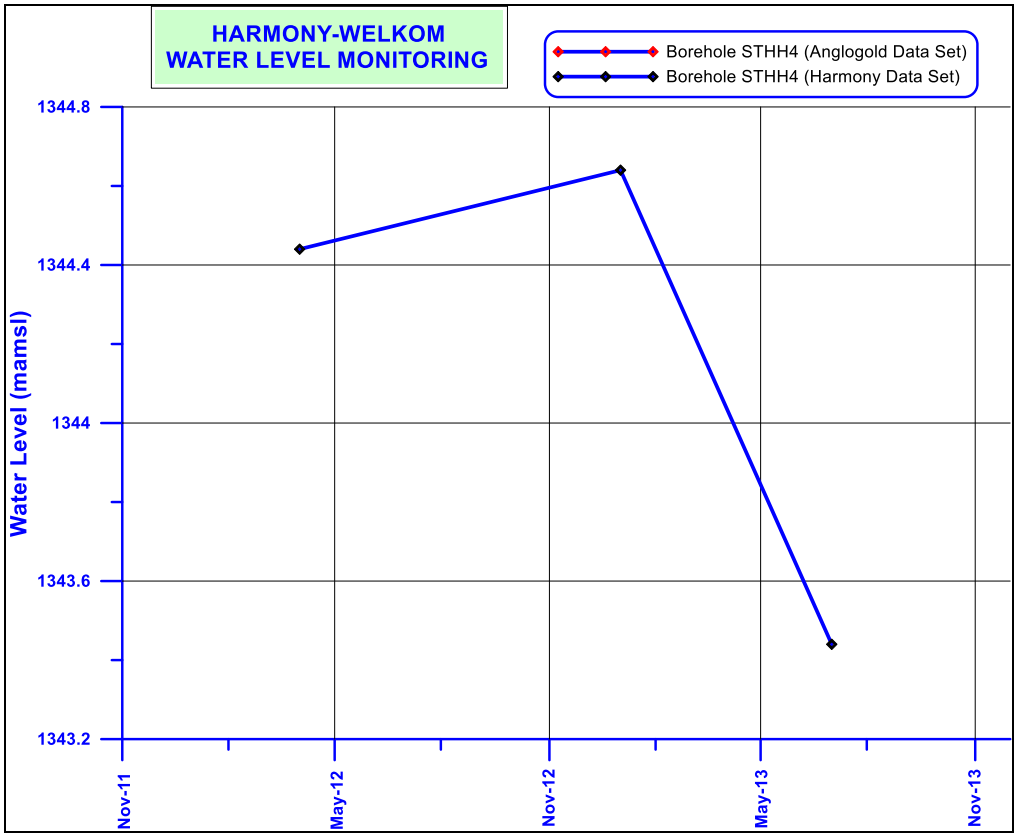

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole KLMJ4 (Anglogold Data Set)
Borehole KLMJ4 (Harmony Data Set)
Water Level (mamsl)
1376
1374
1372
1370
1368
1366
1364
Nov-09
May-10
Nov-10
May-11
Nov-11
May-12
Nov-12

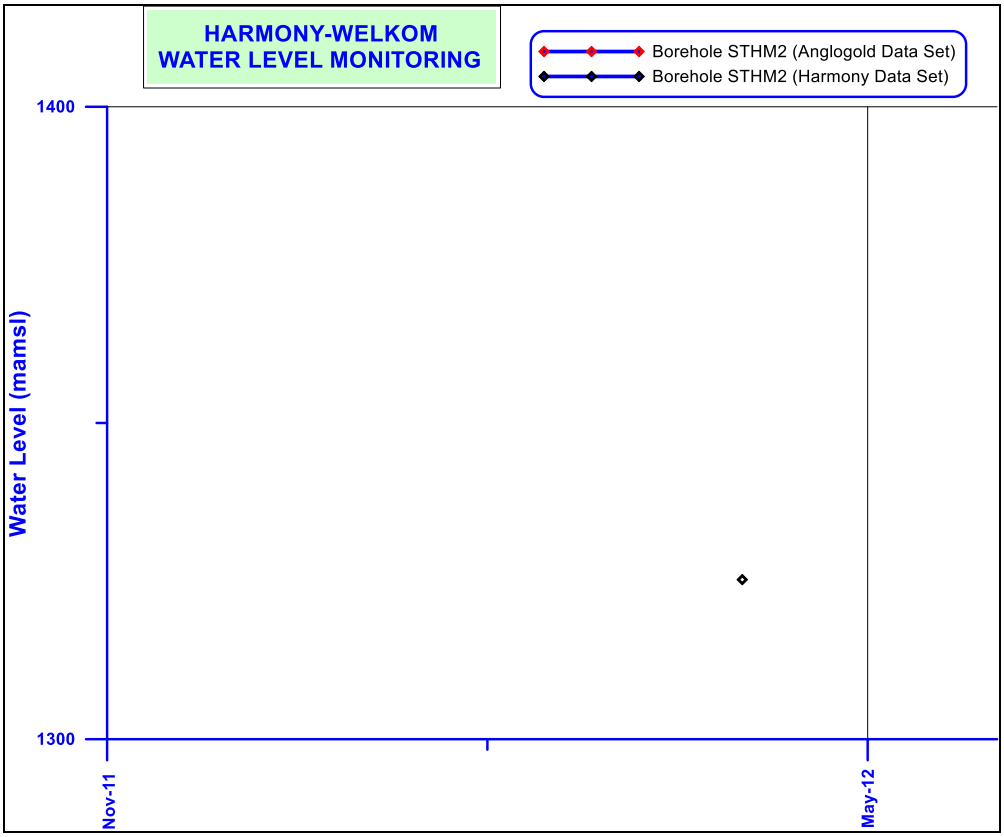

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole P5 (Anglogold Data Set)
Borehole P5 (Harmony Data Set)
Water Level (mamsl)
1362
1360
1358
1356
1354
1352
1350
Dec-06
Jun-07
Dec-07
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13

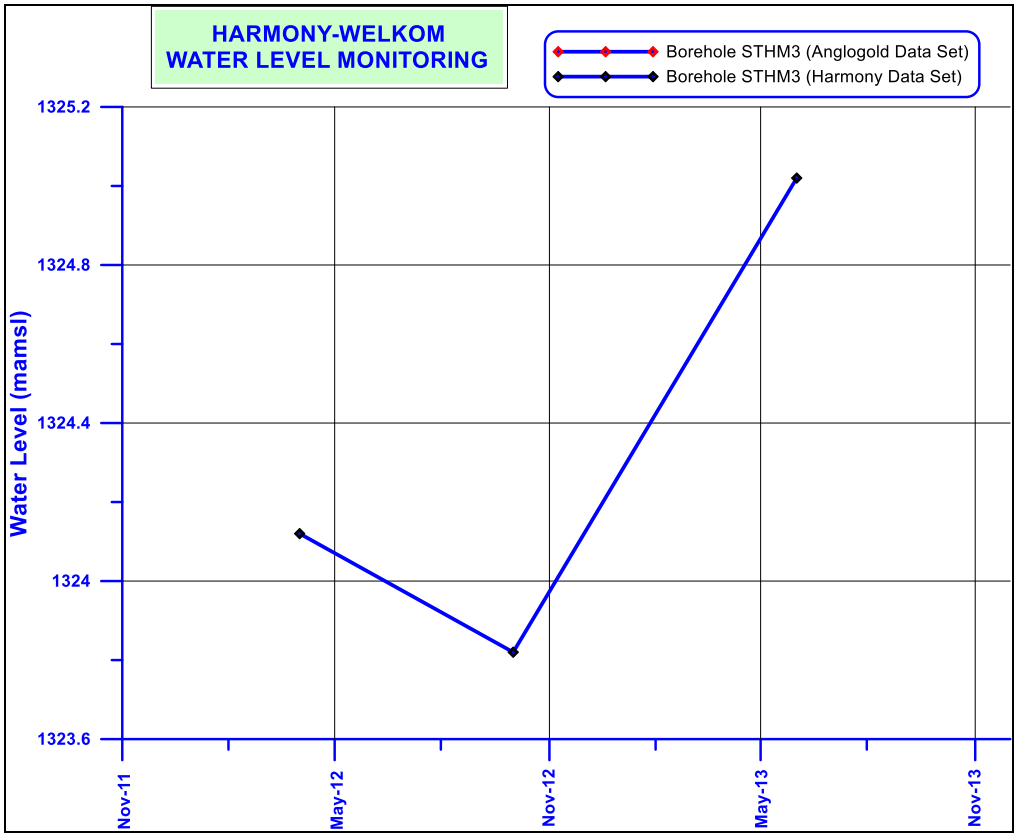

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole P7 (Anglogold Data Set)
Borehole P7 (Harmony Data Set)
Water Level (mamsl)
1361
1360
1359
1358
1357
1356
Dec-06
Jun-07
Dec-07
Jun-08
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13
Dec-13

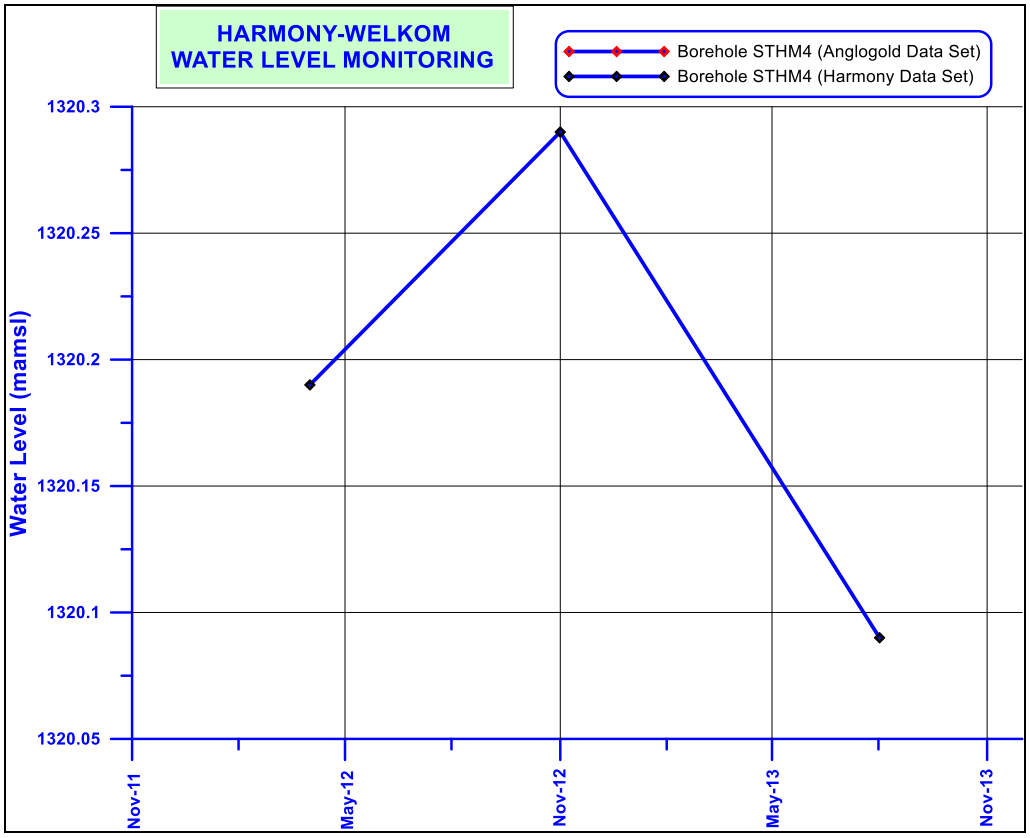

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole STHH2 (Anglogold Data Set)
Borehole STHH2 (Harmony Data Set)
Water Level (mamsl)
1330.5
1330
1329.5
1329
1328.5
1328
Nov-11
May-12
Nov-12
May-13
Nov-13

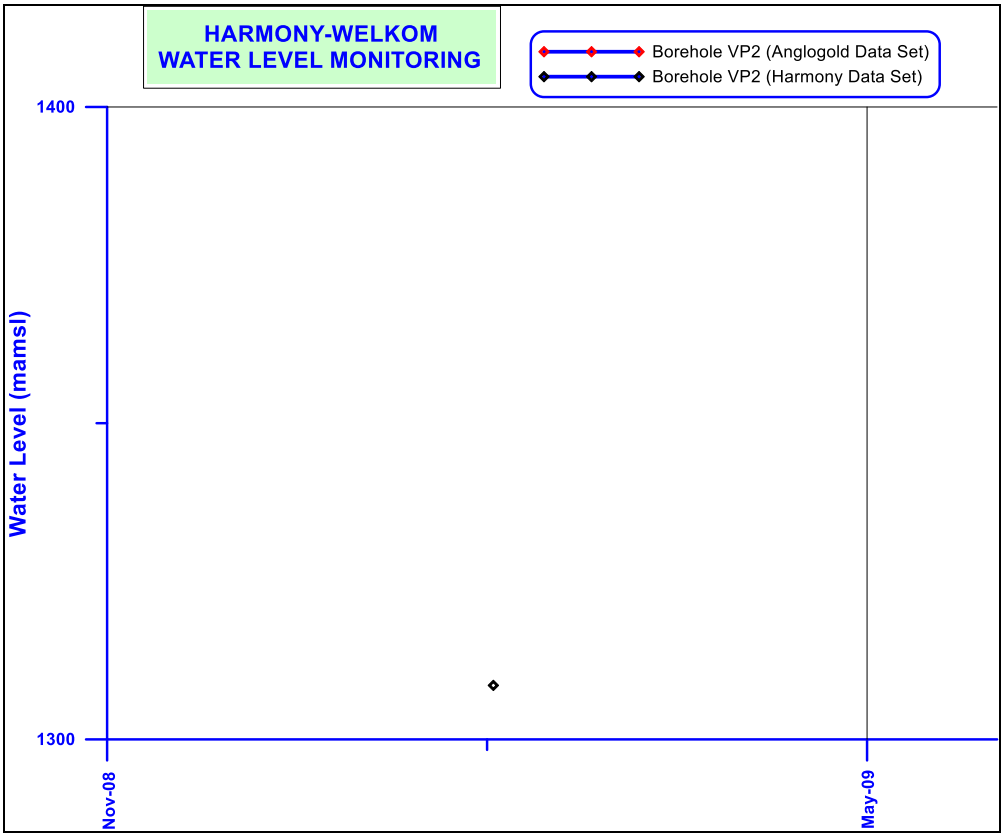

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole STHH3 (Anglogold Data Set)
Borehole STHH3 (Harmony Data Set)
Water Level (mamsl)
1335.4
1335.2
1335
1334.8
1334.6
1334.4
Nov-11
May-12
Nov-12
May-13


HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole STHH4 (Anglogold Data Set)
Borehole STHH4 (Harmony Data Set)
Water Level (mamsl)
1344.8
1344.4
1344
1343.6
1343.2
Nov-11
May-12
Nov-12
May-13
Nov-13

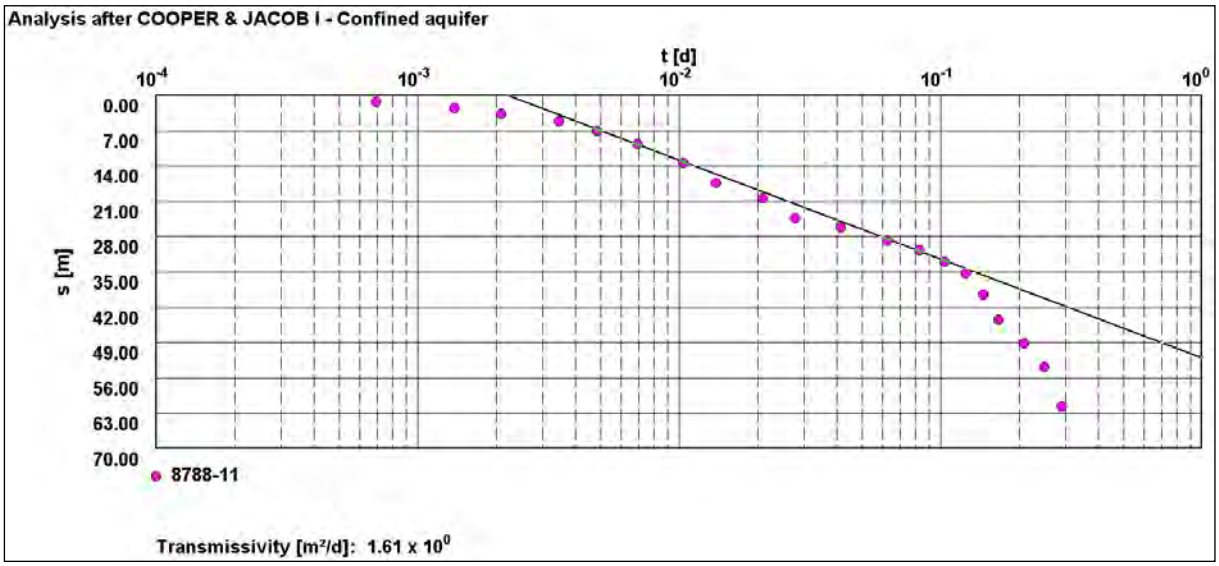

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole STHM2 (Anglogold Data Set)
Borehole STHM2 (Harmony Data Set)
Water Level (mamsl)
1400
1300
Nov-11
May-12

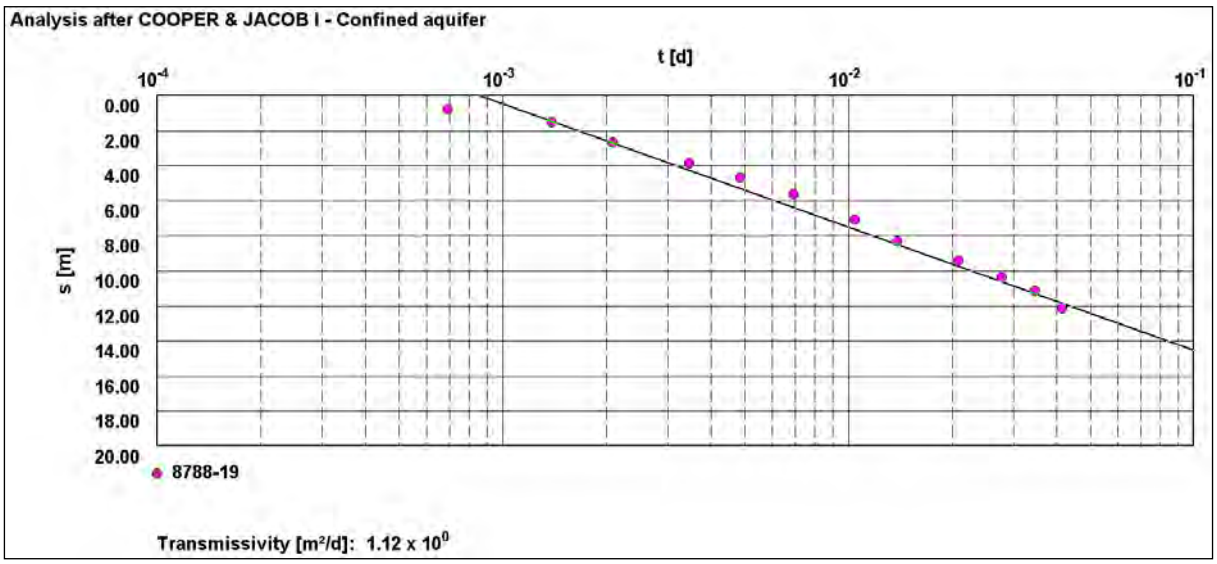

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole STHM3 (Anglogold Data Set)
Borehole STHM3 (Harmony Data Set)
Water Level (mamsl)
1325.2
1324.8
1324.4
1324
1323.6
Nov-11
May-12
Nov-12
May-13
Nov-13

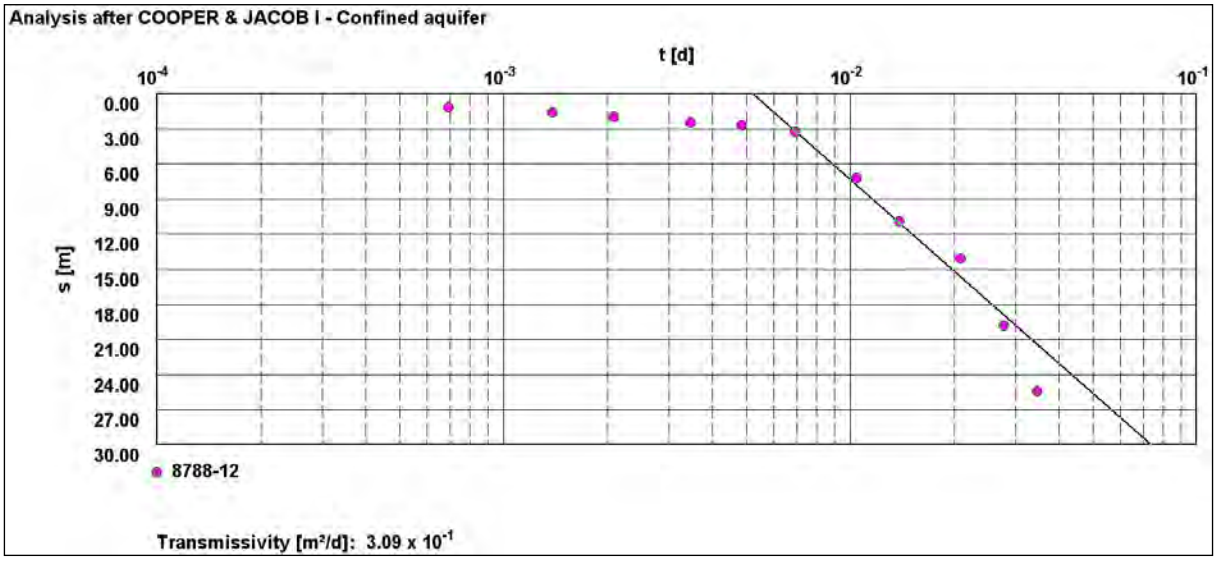

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole STHM4 (Anglogold Data Set)
Borehole STHM4 (Harmony Data Set)
Water Level (mamsl)
1320.3
1320.25
1320.2
1320.15
1320.1
1320.05
Nov-11
May-12
Nov-12
May-13
Nov-13

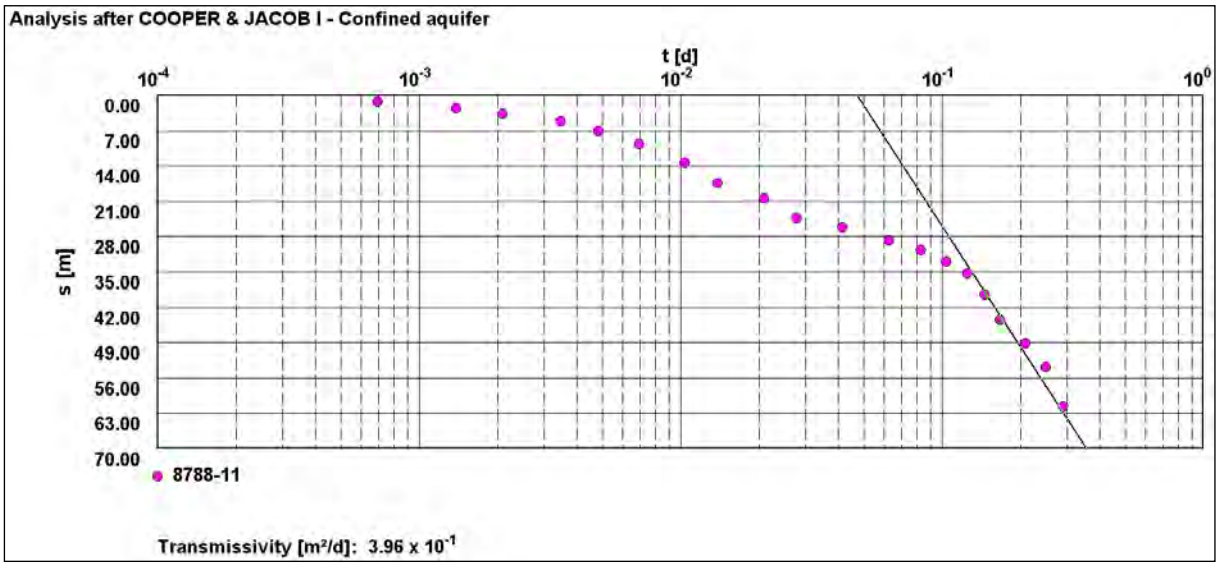

HARMONY-WELKOM
WATER LEVEL MONITORING
Borehole VP2 (Anglogold Data Set)
Borehole VP2 (Harmony Data Set)
1400
1300
Water Level (mamsl)
Nov-08
May-09

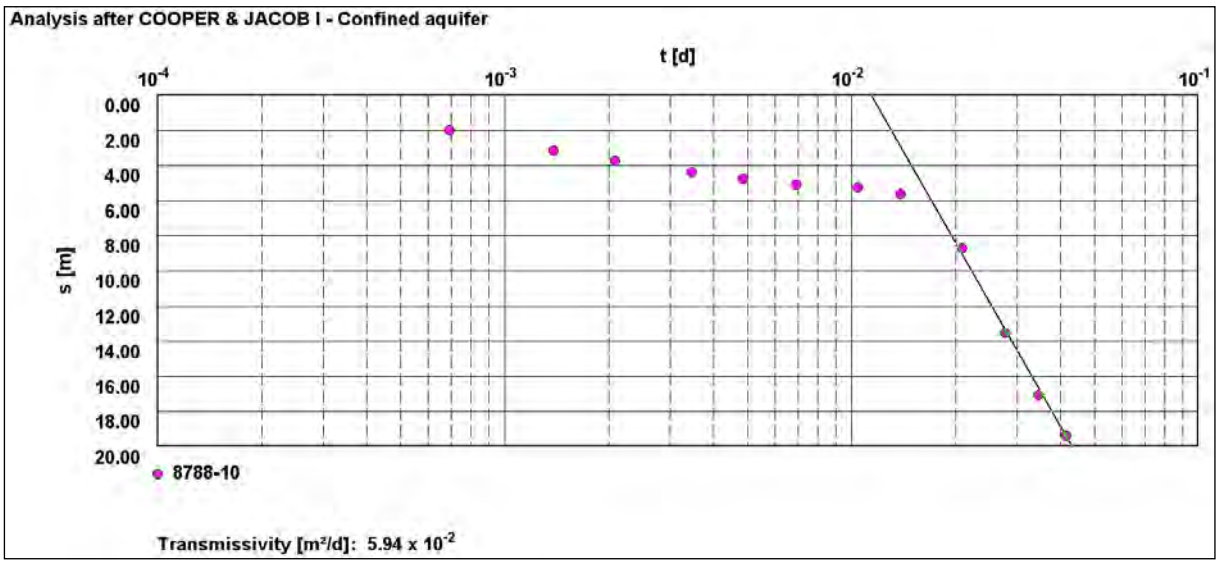
Appendix II
Welkom Harmony - Aquifer Test Analysis

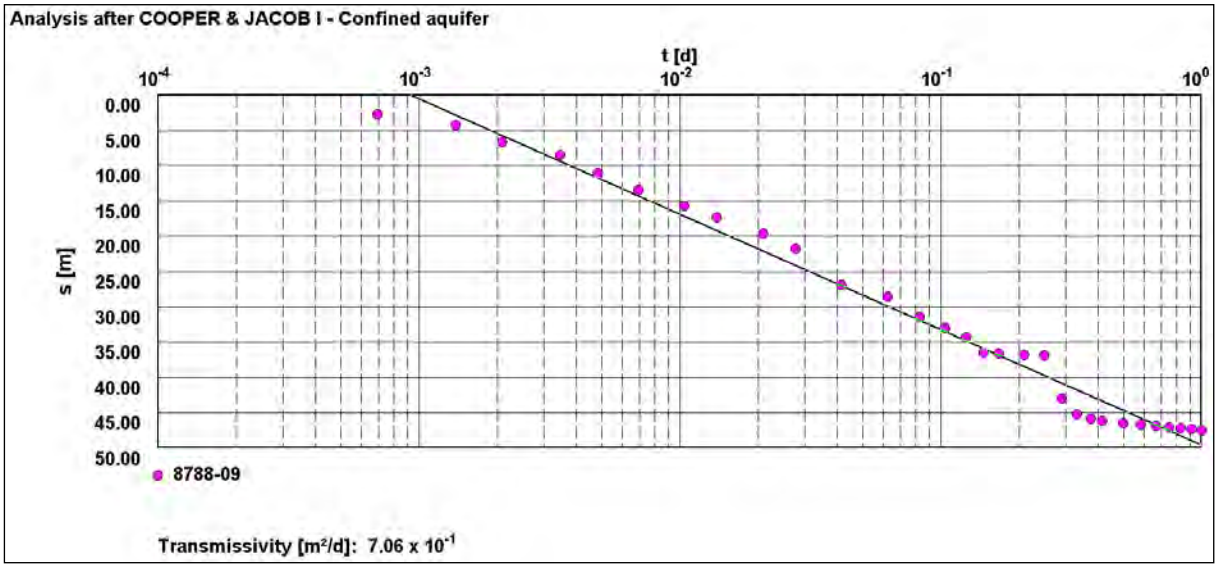

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
100
s [m]
0.00
7.00
14.00
21.00
28.00
35.00
42.00
49.00
56.00
63.00
70.00
8788-11
Transmissivity [m²/d]: 1.61 x 10⁰

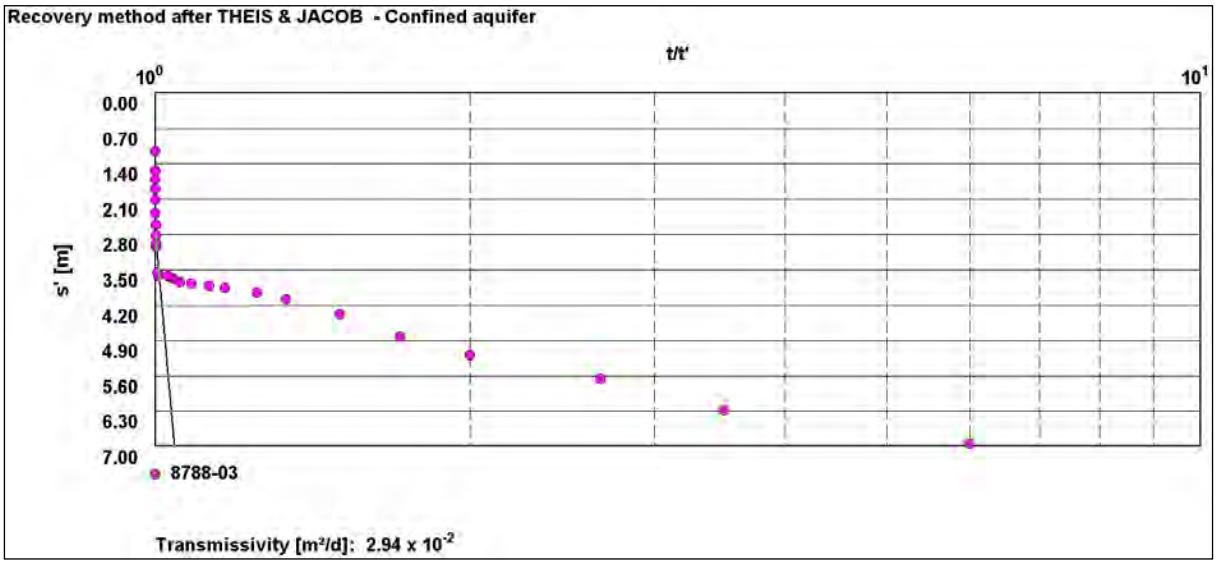

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
s [m]
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
8788-19
Transmissivity [m²/d]: 1.12 x 10⁰

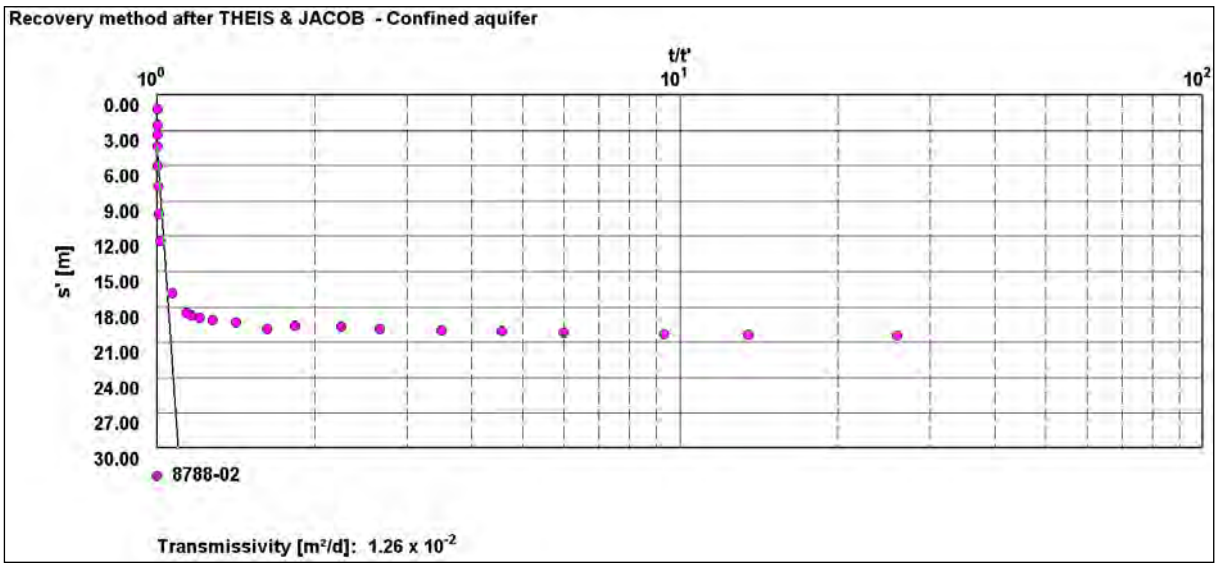

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
s [m]
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
8788-12
Transmissivity [m²/d]: 3.09 x 10⁻¹

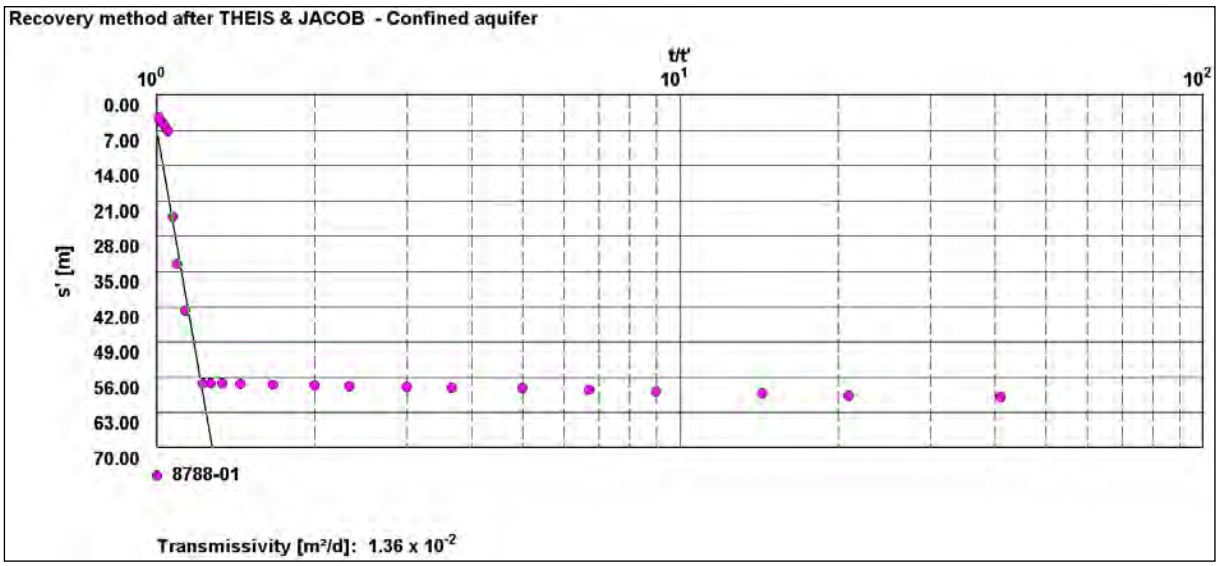

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
100
s [m]
0.00
7.00
14.00
21.00
28.00
35.00
42.00
49.00
56.00
63.00
70.00
8788-11
Transmissivity [m²/d]: 3.96 x 10-1


Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
s [m]
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
8788-10
Transmissivity [m²/d]: 5.94 x 10-2

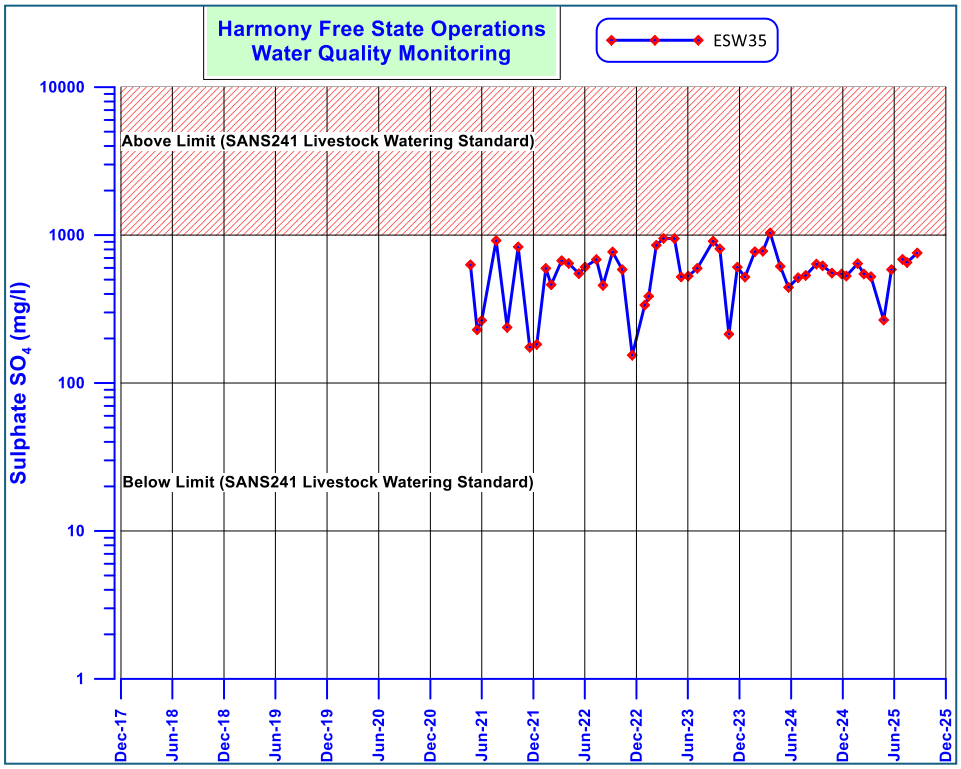

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
100
s [m]
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
8788-09
Transmissivity [m²/d]: 7.06 x 10-1

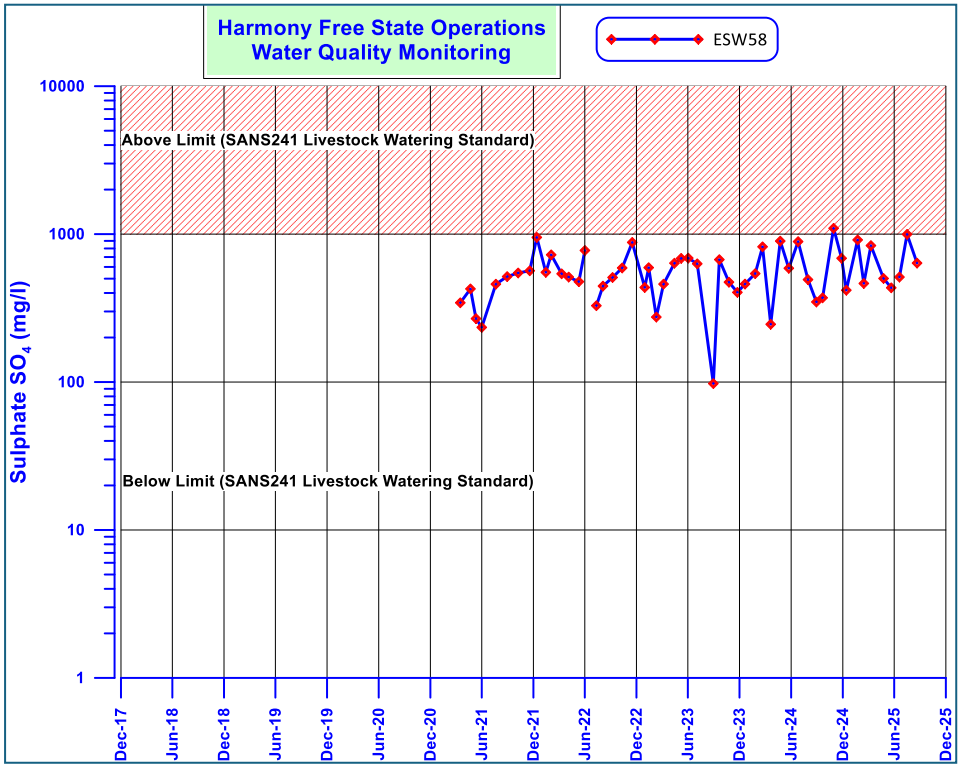

Recovery method after THEIS & JACOB - Confined aquifer
t/t'
10^0
10^1
s' [m]
0.00
0.70
1.40
2.10
2.80
3.50
4.20
4.90
5.60
6.30
7.00
8788-03
Transmissivity [m²/d]: 2.94 x 10^-2

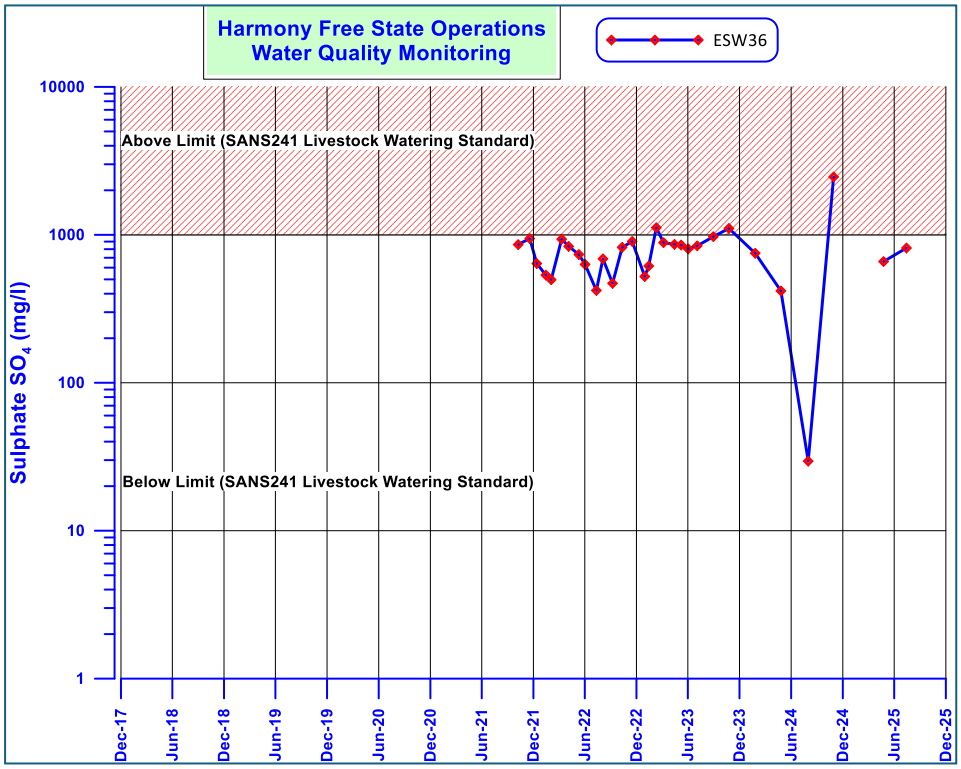

Recovery method after THEIS & JACOB - Confined aquifer
t/t'
10^0
10^1
10^2
s' [m]
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
8788-02
Transmissivity [m²/d]: 1.26 x 10^-2

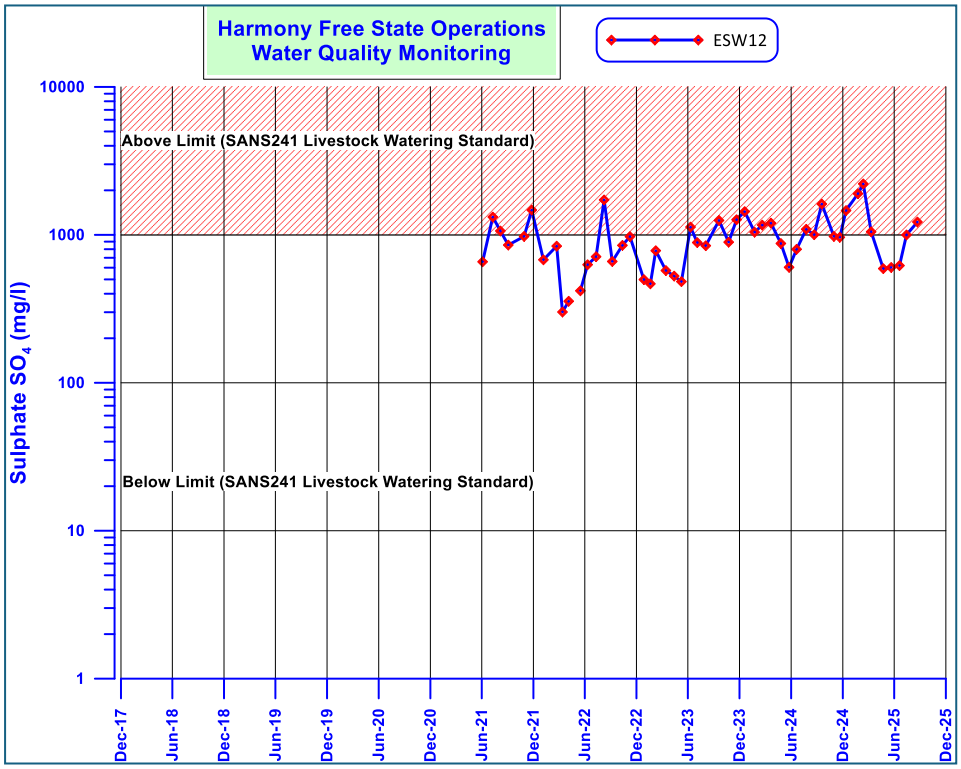

Recovery method after THEIS & JACOB - Confined aquifer
t/t'
10^0
10^1
10^2
s' [m]
0.00
7.00
14.00
21.00
28.00
35.00
42.00
49.00
56.00
63.00
70.00
8788-01
Transmissivity [m²/d]: 1.36 x 10^-2

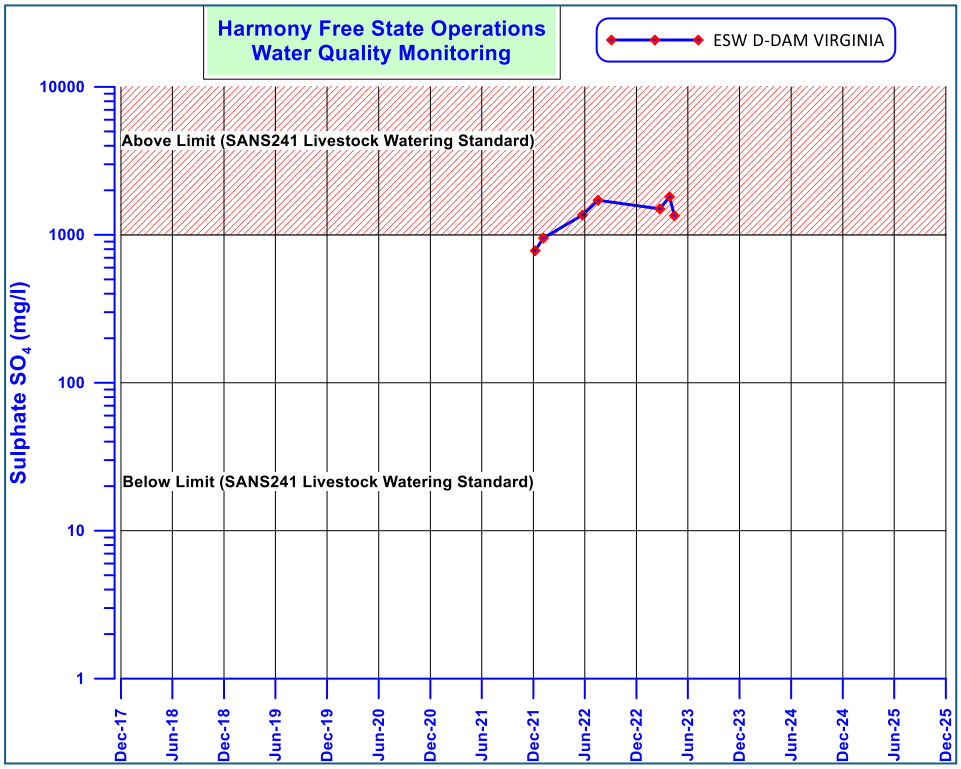
Appendix III
Welkom Harmony – Observed Sulphate Concentrations at Surface Monitoring Points

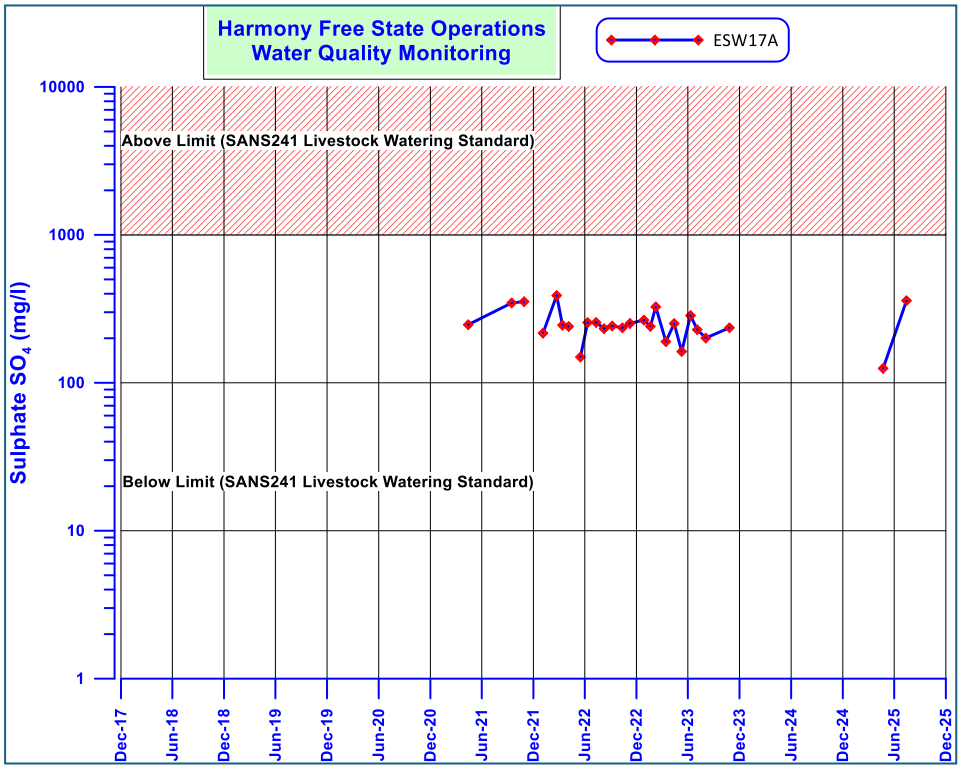

Harmony Free State Operations
Water Quality Monitoring
ESW35
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

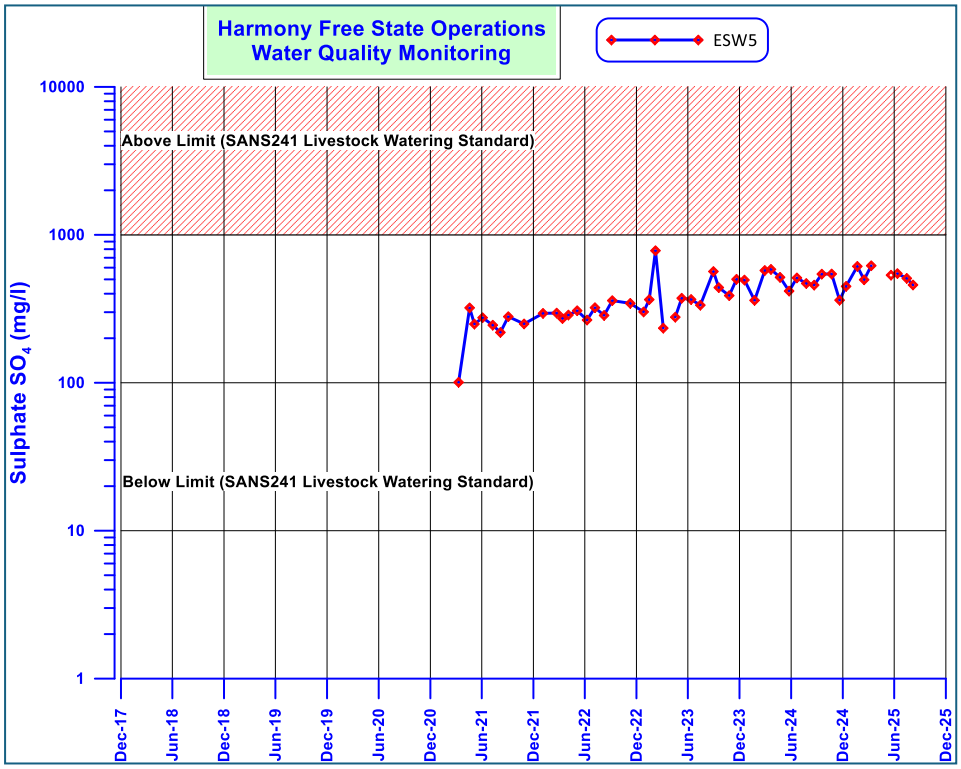

Harmony Free State Operations
Water Quality Monitoring
ESW58
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

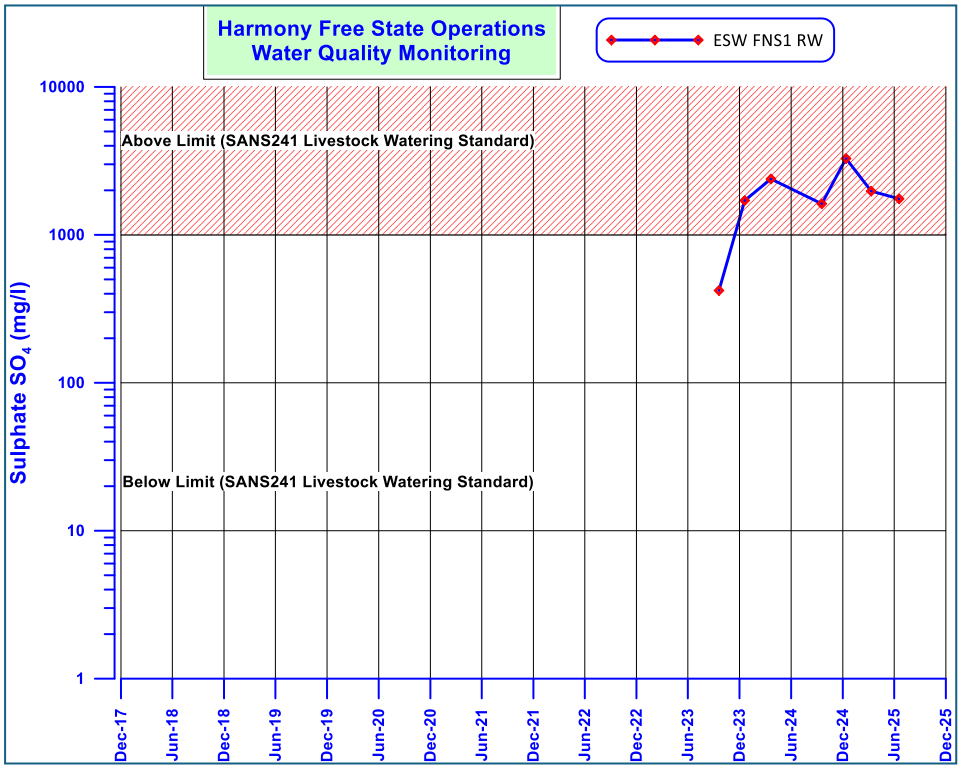

Harmony Free State Operations
Water Quality Monitoring
ESW36
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

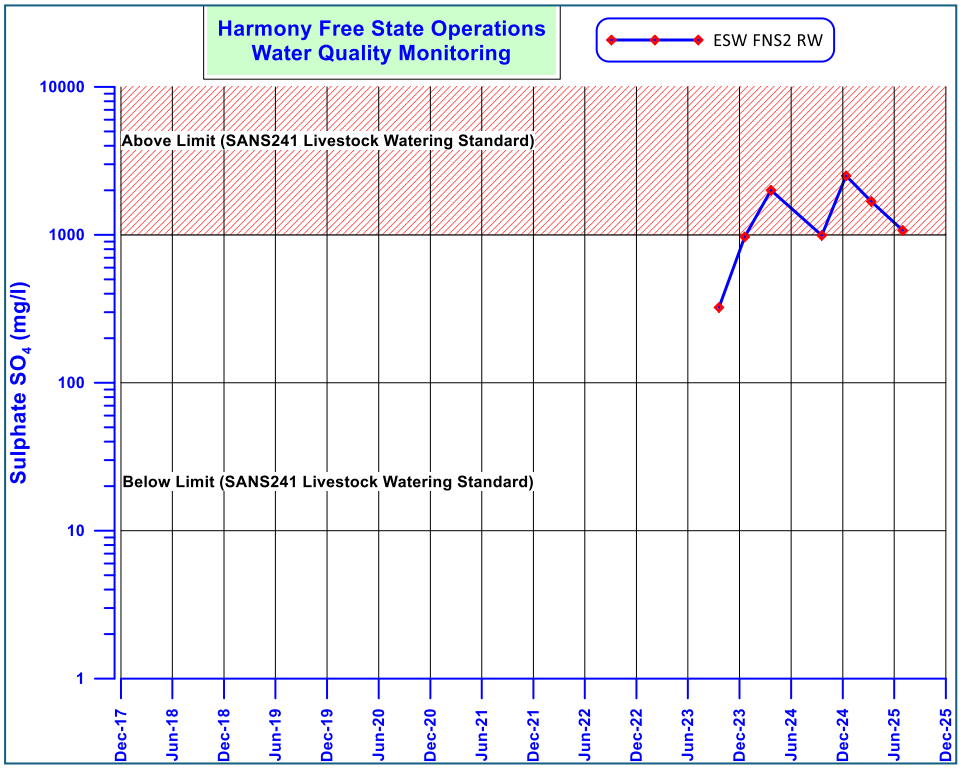

Harmony Free State Operations
Water Quality Monitoring
ESW12
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

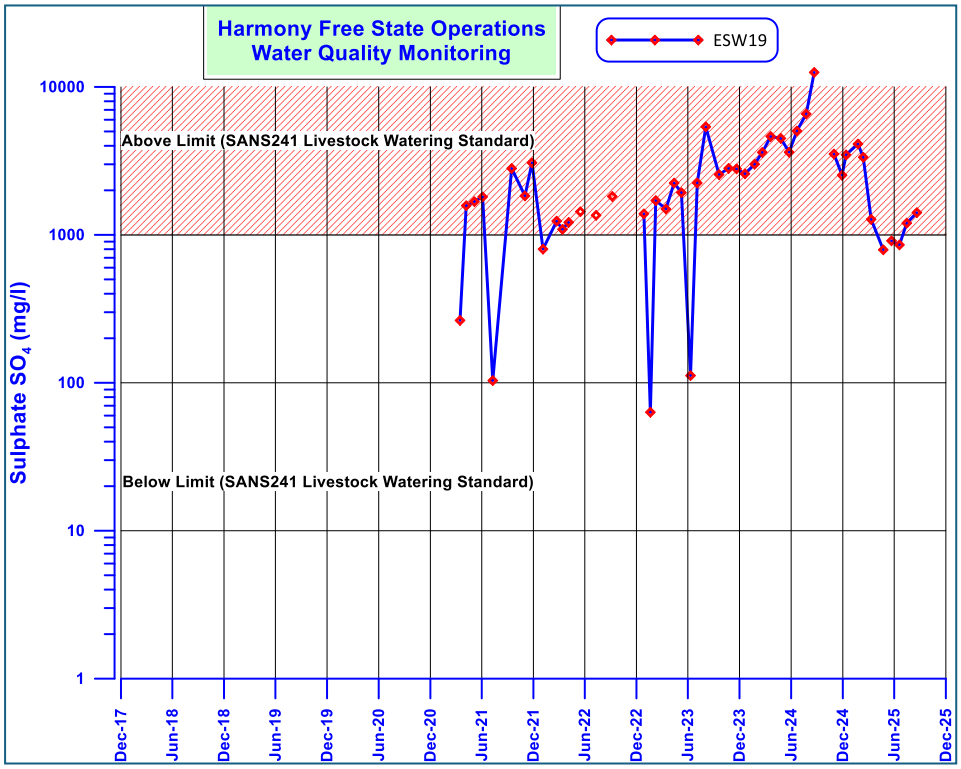

Harmony Free State Operations
Water Quality Monitoring
ESW D-DAM VIRGINIA
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

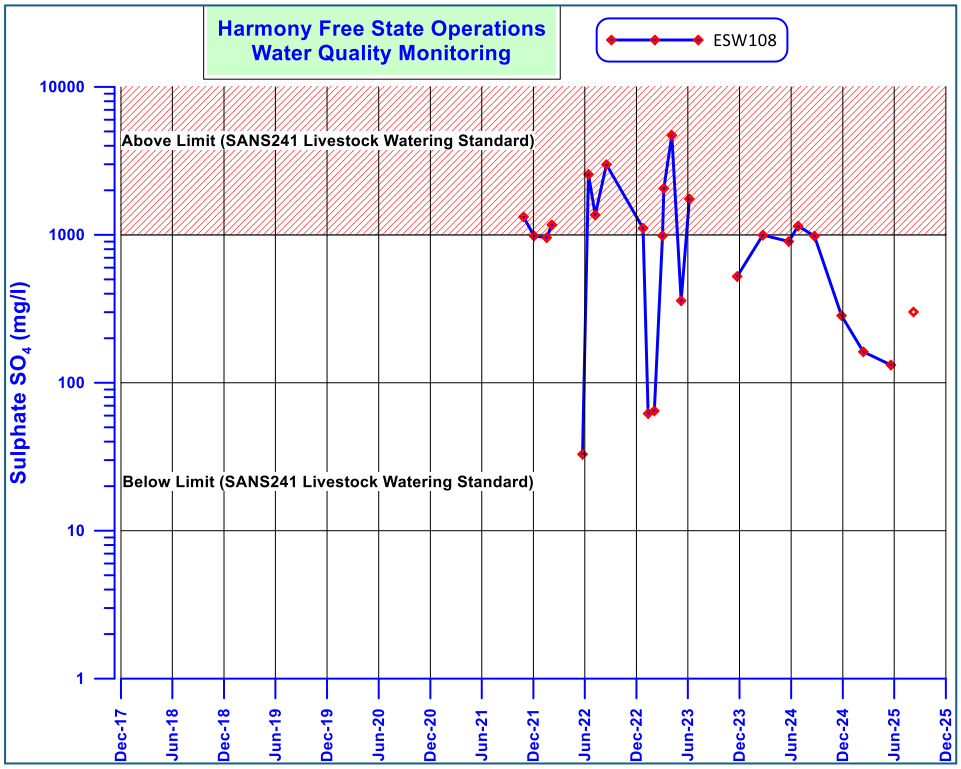

Harmony Free State Operations
Water Quality Monitoring
ESW17A
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

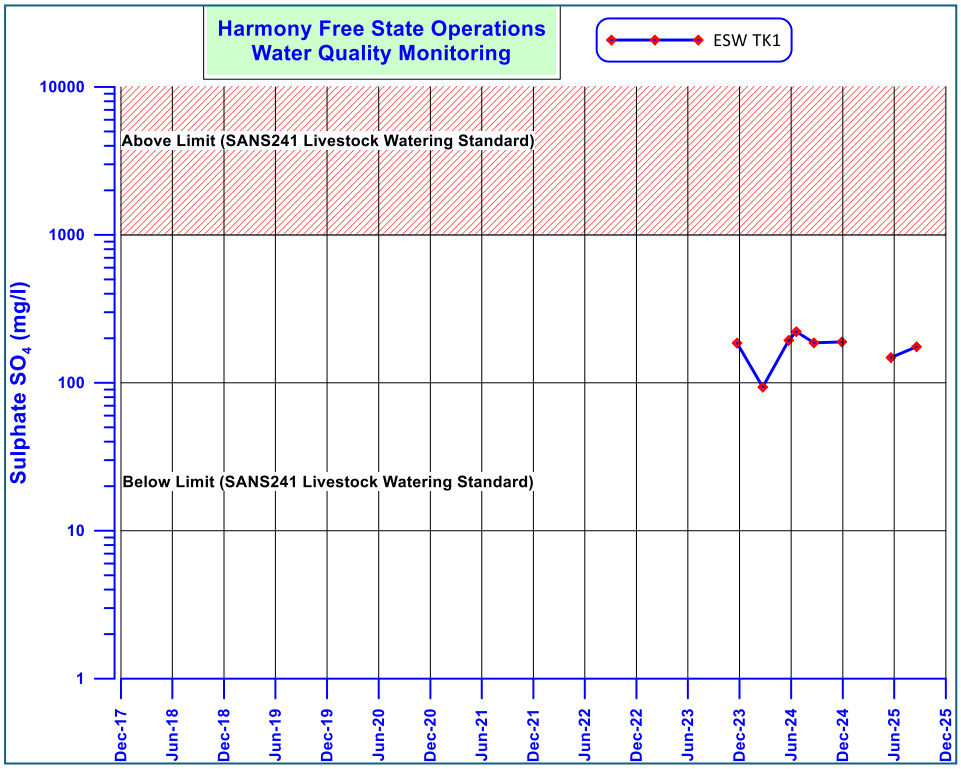

Harmony Free State Operations
Water Quality Monitoring
ESW5
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

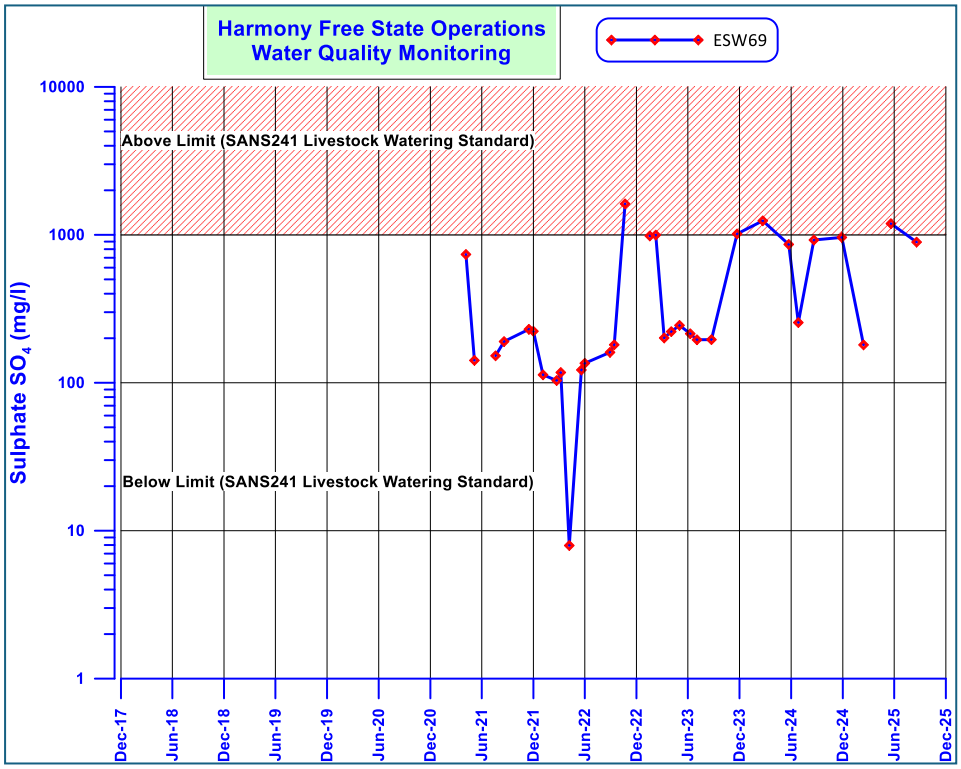

Harmony Free State Operations
Water Quality Monitoring
ESW FNS1 RW
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

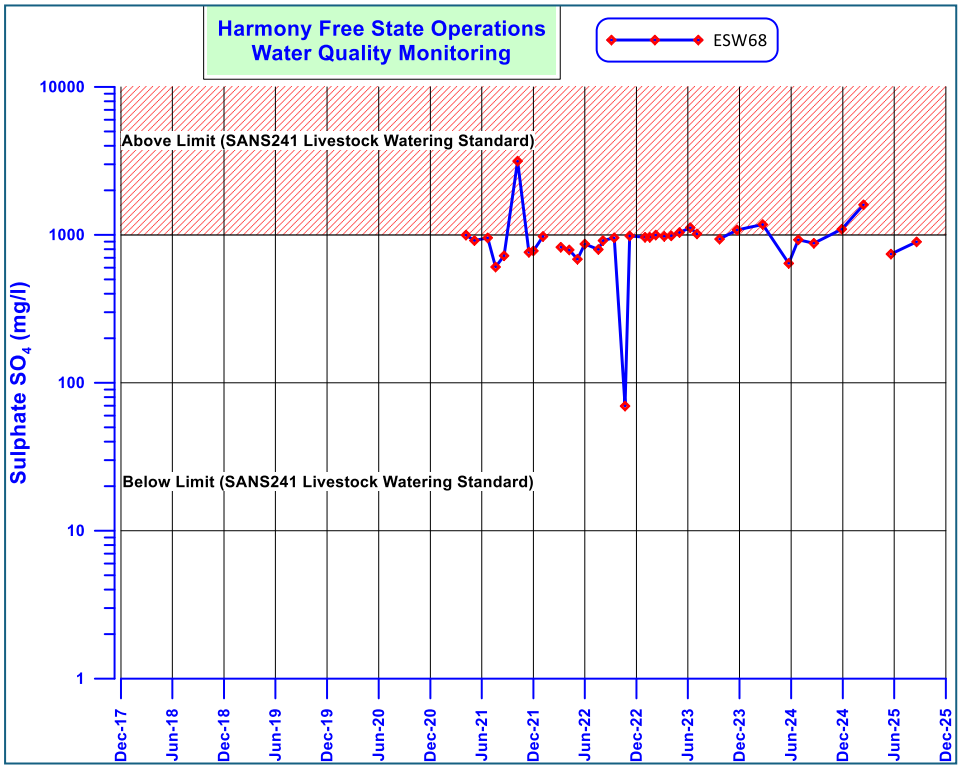

Harmony Free State Operations
Water Quality Monitoring
ESW FNS2 RW
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

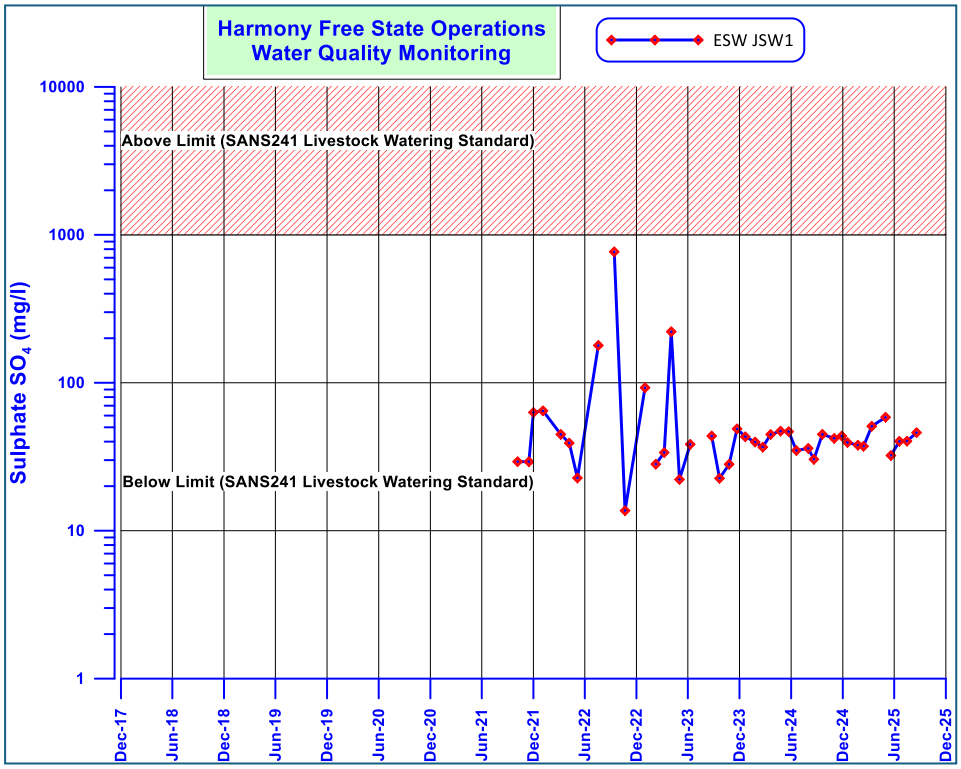

Harmony Free State Operations
Water Quality Monitoring
ESW19
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

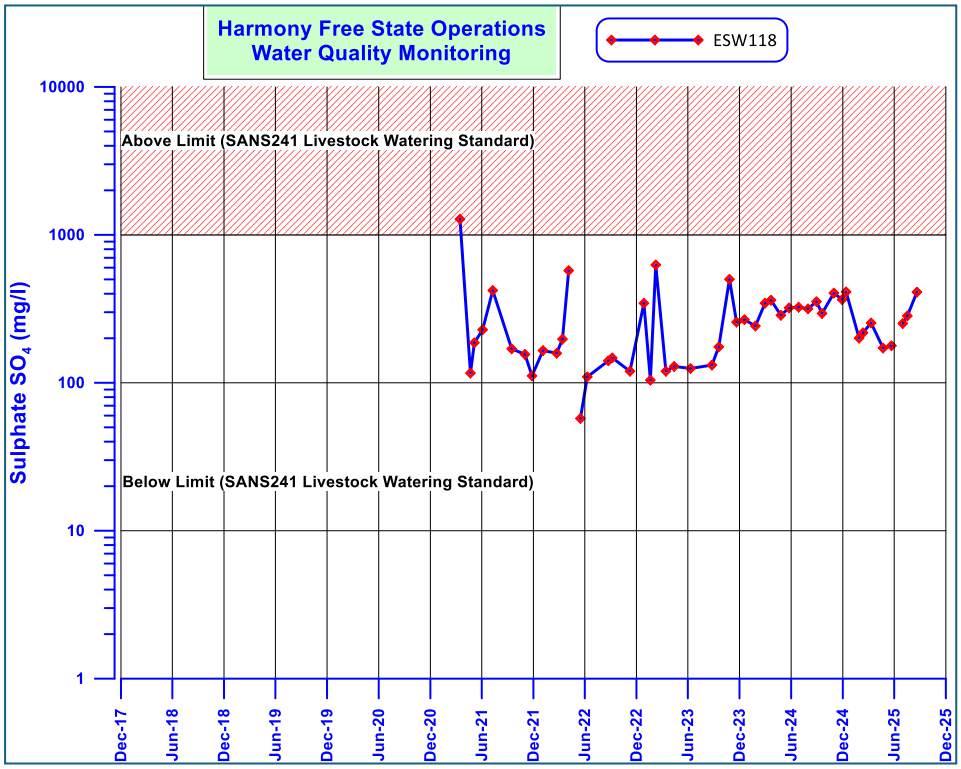

Harmony Free State Operations
Water Quality Monitoring
ESW108
Sulphate SO_4 (mg/l)
10000
1000
100
10
1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

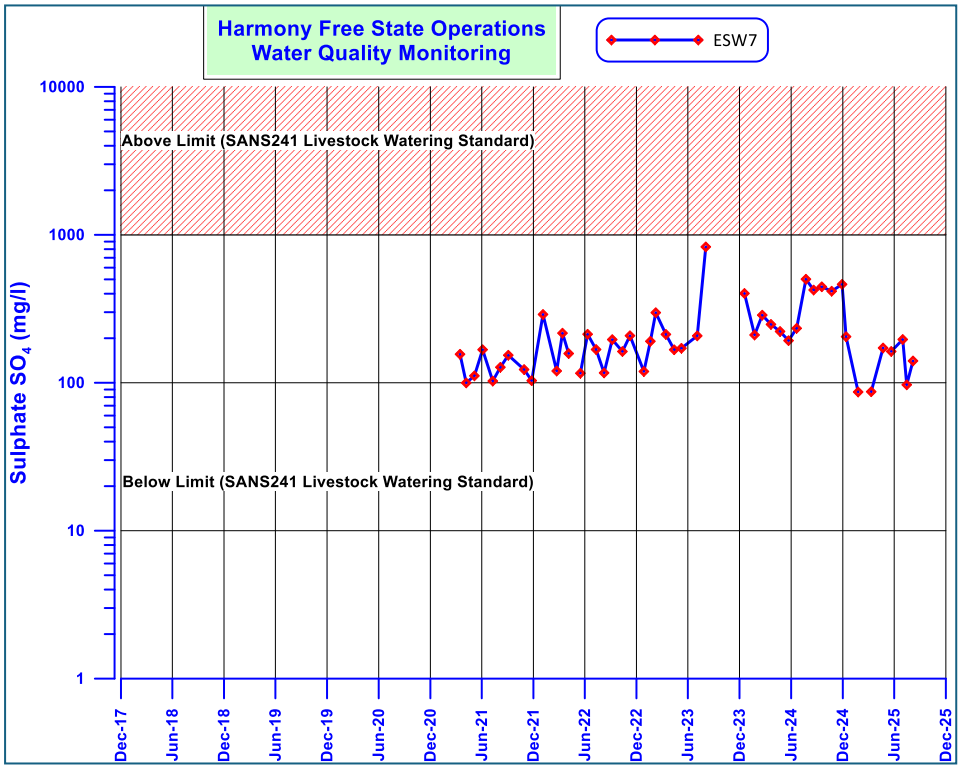

Harmony Free State Operations
Water Quality Monitoring
ESW TK1
Sulphate SO_4 (mg/l)
10000
1000
100
10
1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

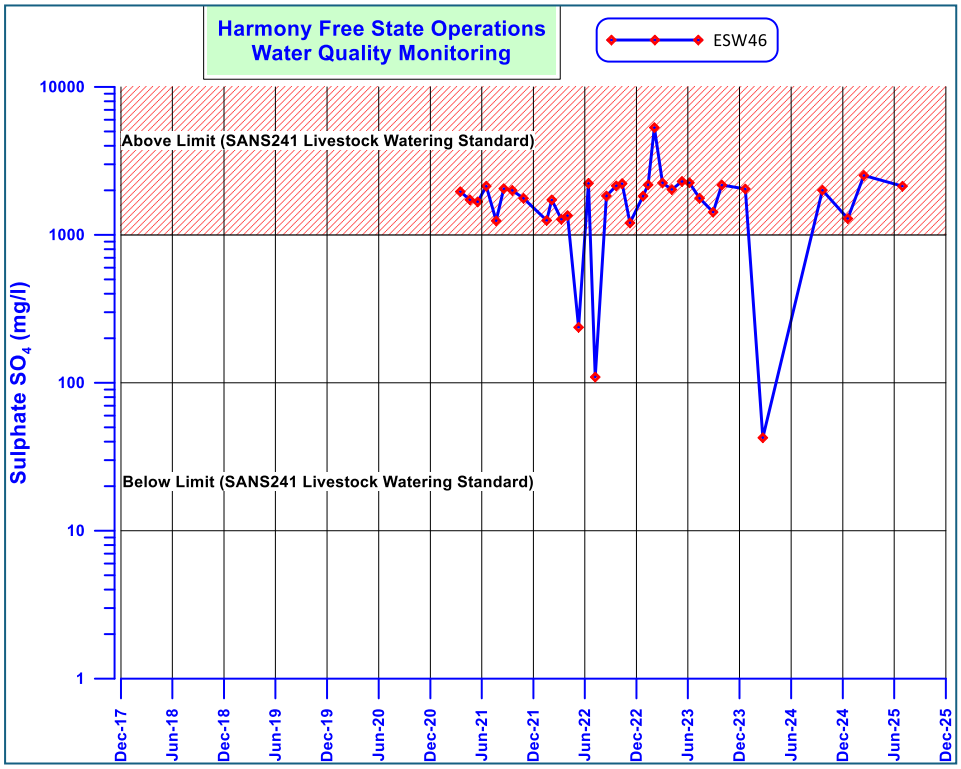

Harmony Free State Operations
Water Quality Monitoring
ESW69
Sulphate SO_4 (mg/l)
10000
1000
100
10
1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

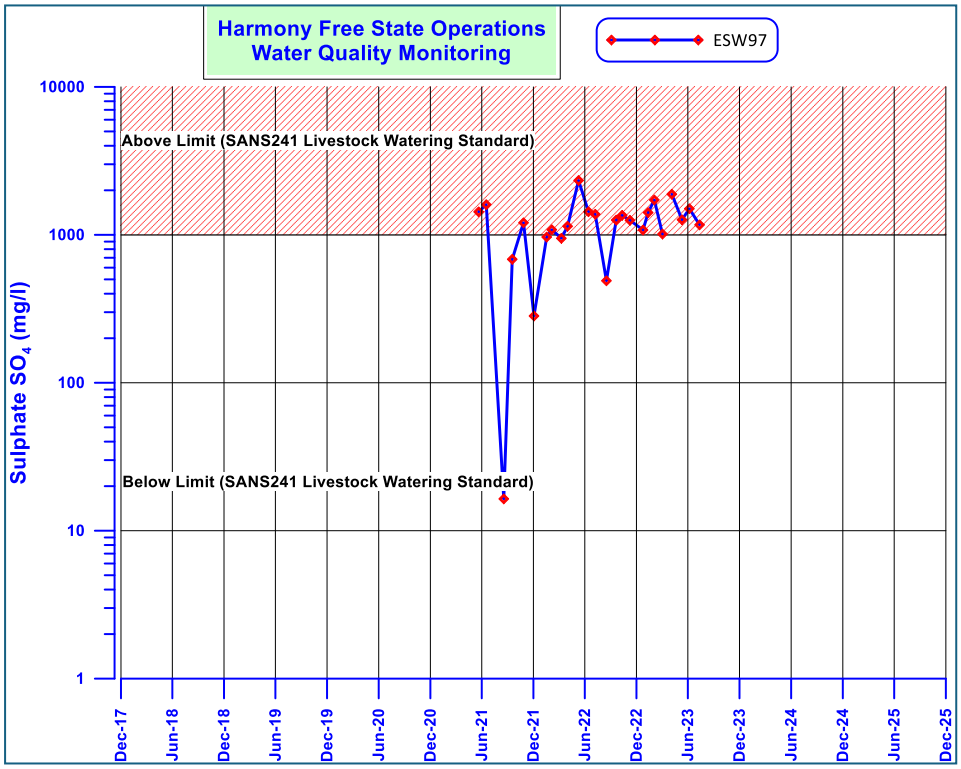

Harmony Free State Operations
Water Quality Monitoring
ESW68
Sulphate SO_4 (mg/l)
10000
1000
100
10
1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

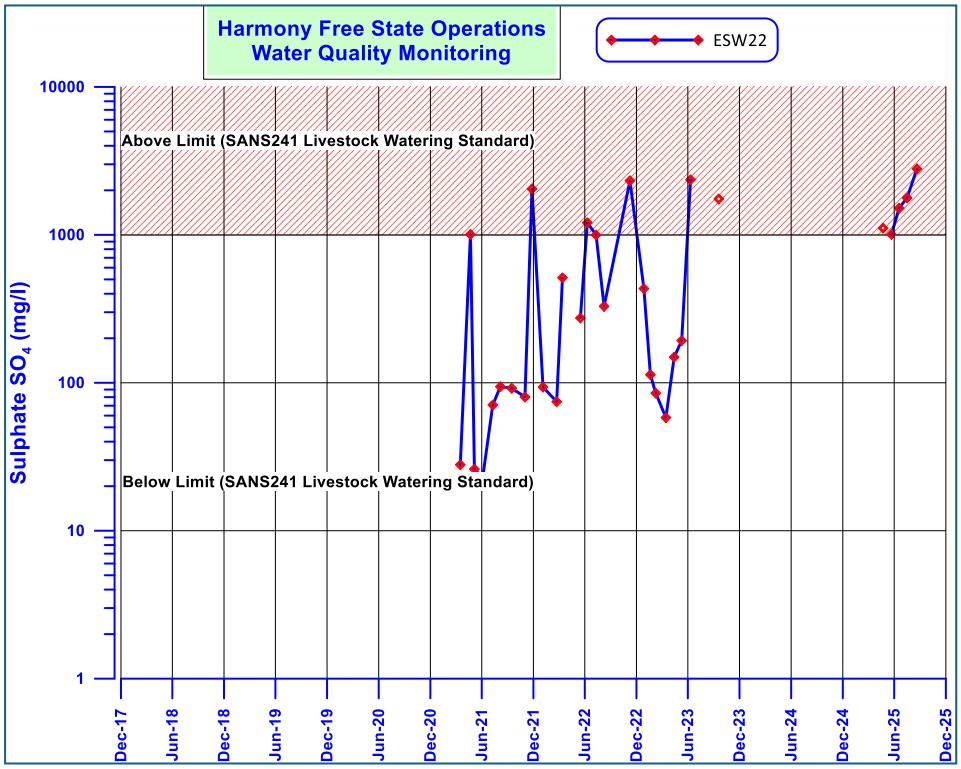

Harmony Free State Operations
Water Quality Monitoring
ESW JSW1
Sulphate SO_4 (mg/l)
10000
1000
100
10
1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

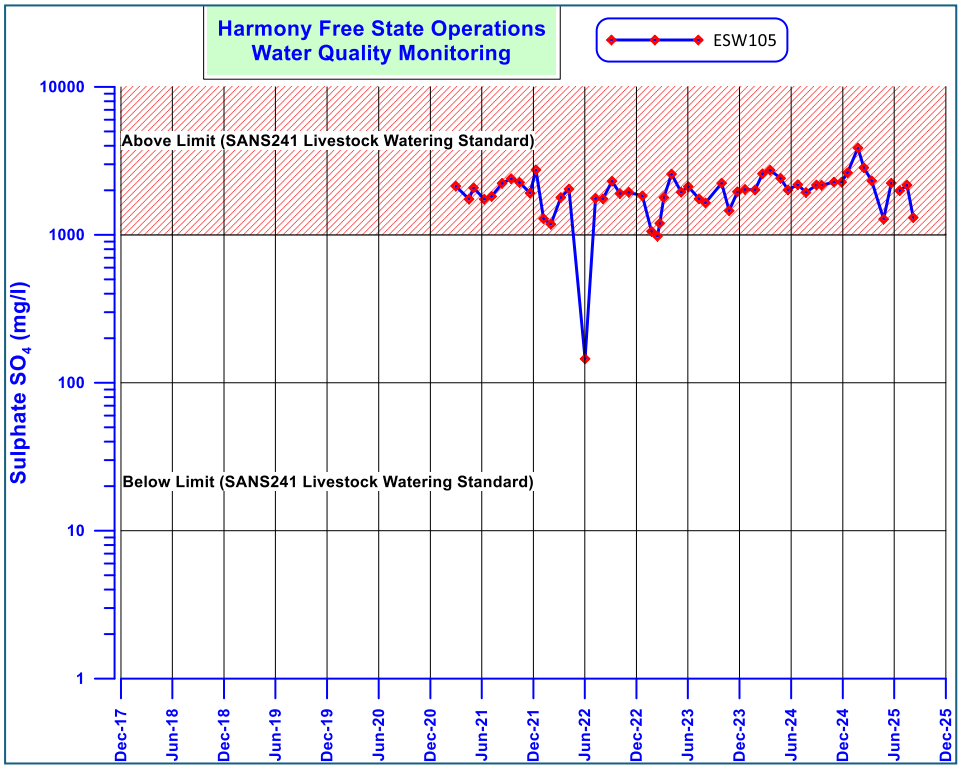

Harmony Free State Operations
Water Quality Monitoring
ESW118
Sulphate SO_4 (mg/l)
10000
1000
100
10
1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

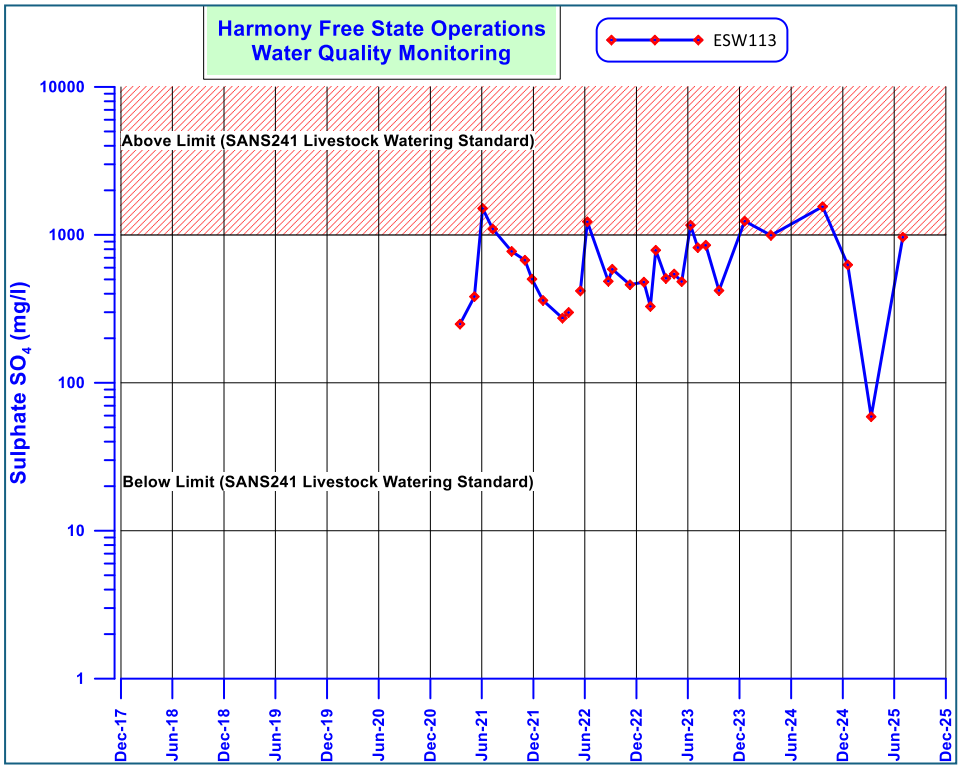

Harmony Free State Operations
Water Quality Monitoring
ESW7
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

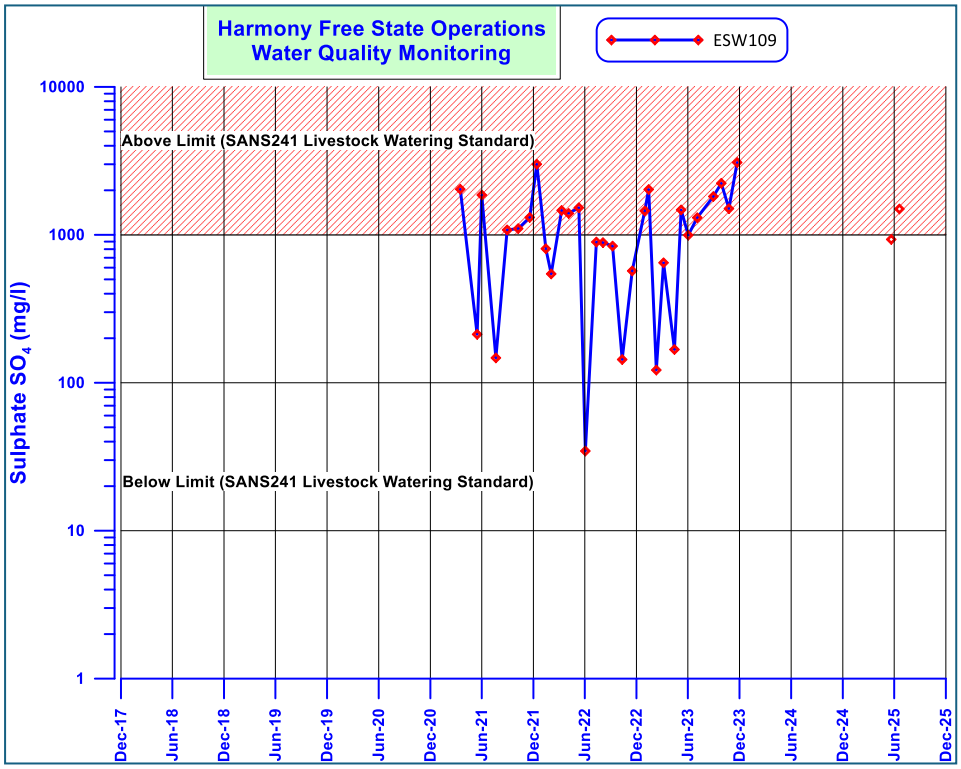

Harmony Free State Operations
Water Quality Monitoring
ESW46
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

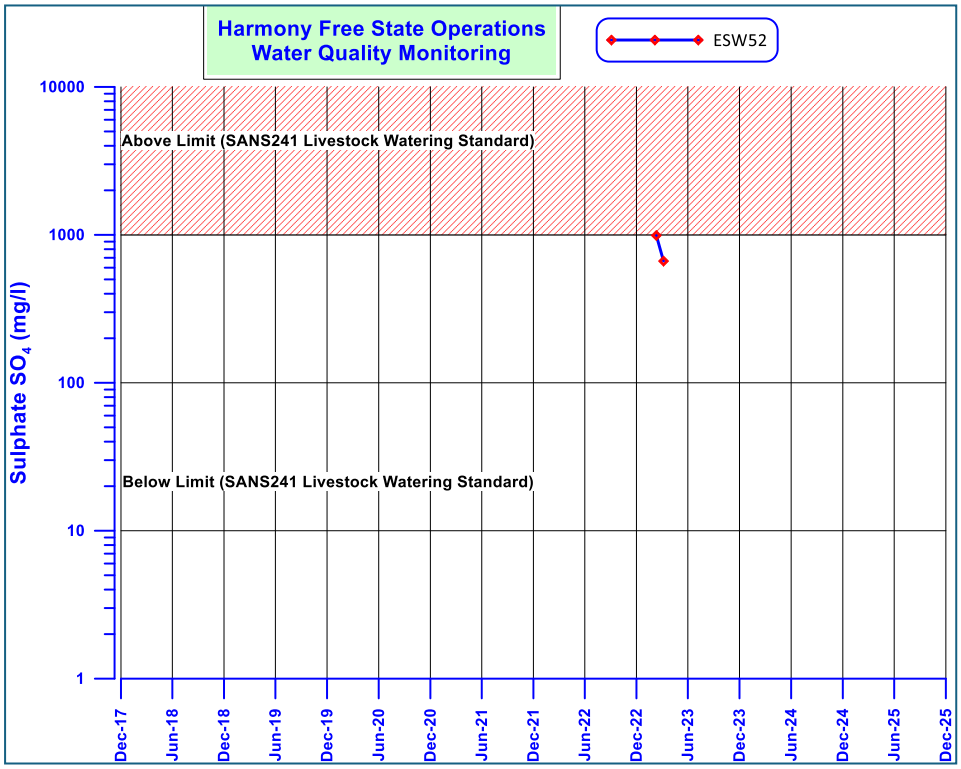

Harmony Free State Operations
Water Quality Monitoring
ESW97
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

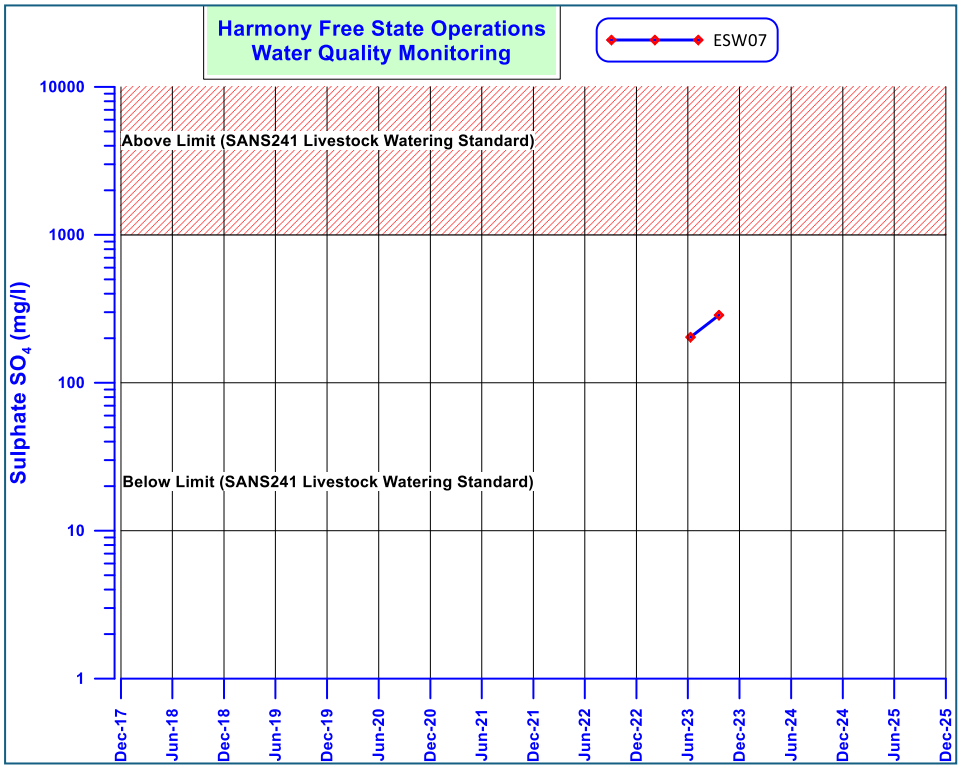

Harmony Free State Operations
Water Quality Monitoring
ESW22
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25


Harmony Free State Operations
Water Quality Monitoring
ESW105
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

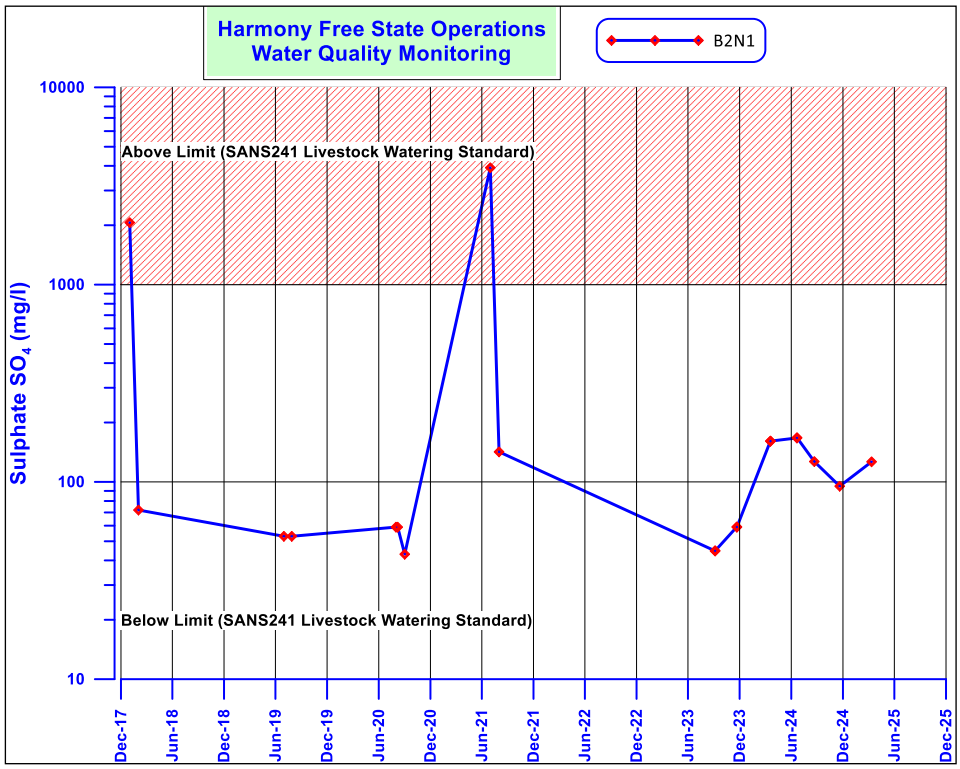

Harmony Free State Operations
Water Quality Monitoring
ESW113
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

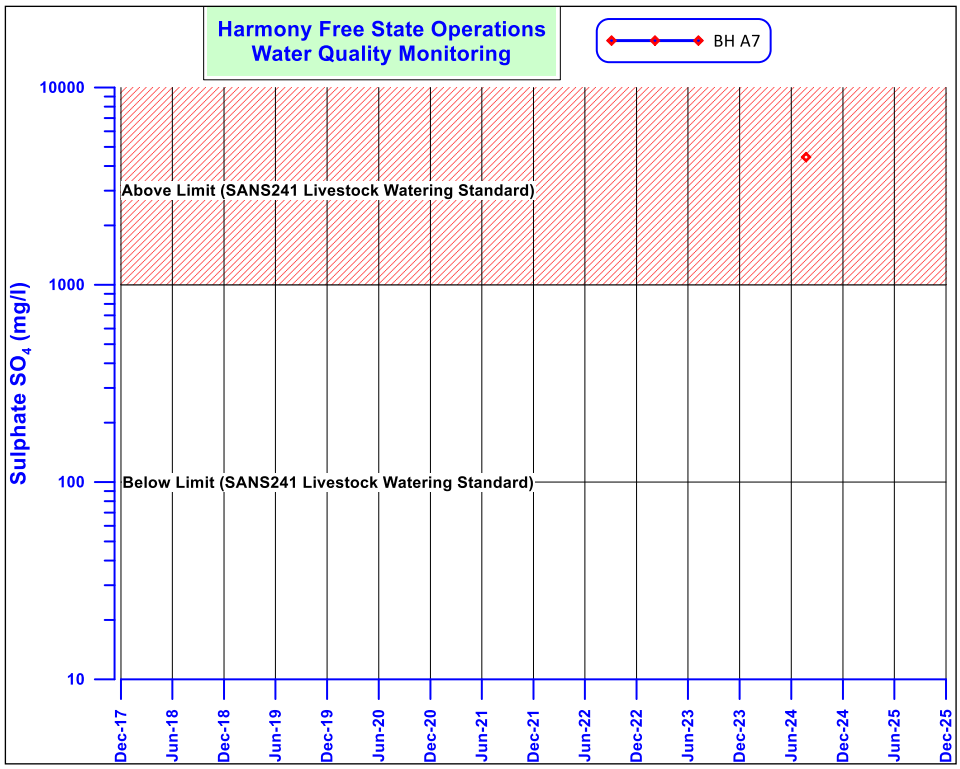

Harmony Free State Operations
Water Quality Monitoring
ESW109
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

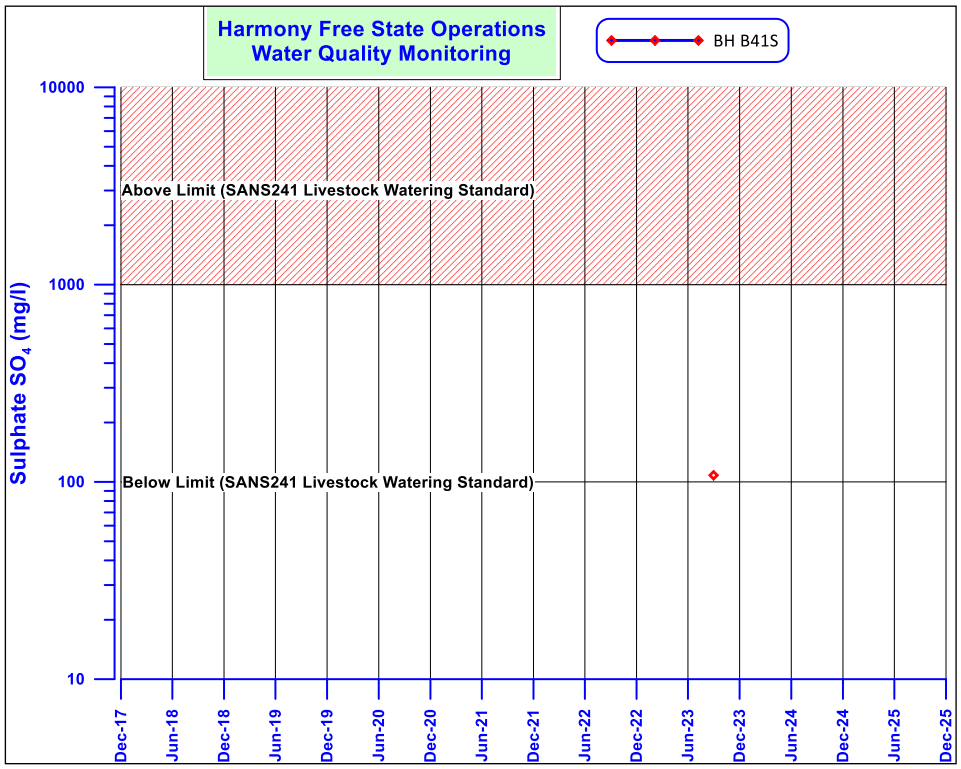

Harmony Free State Operations
Water Quality Monitoring
ESW52
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

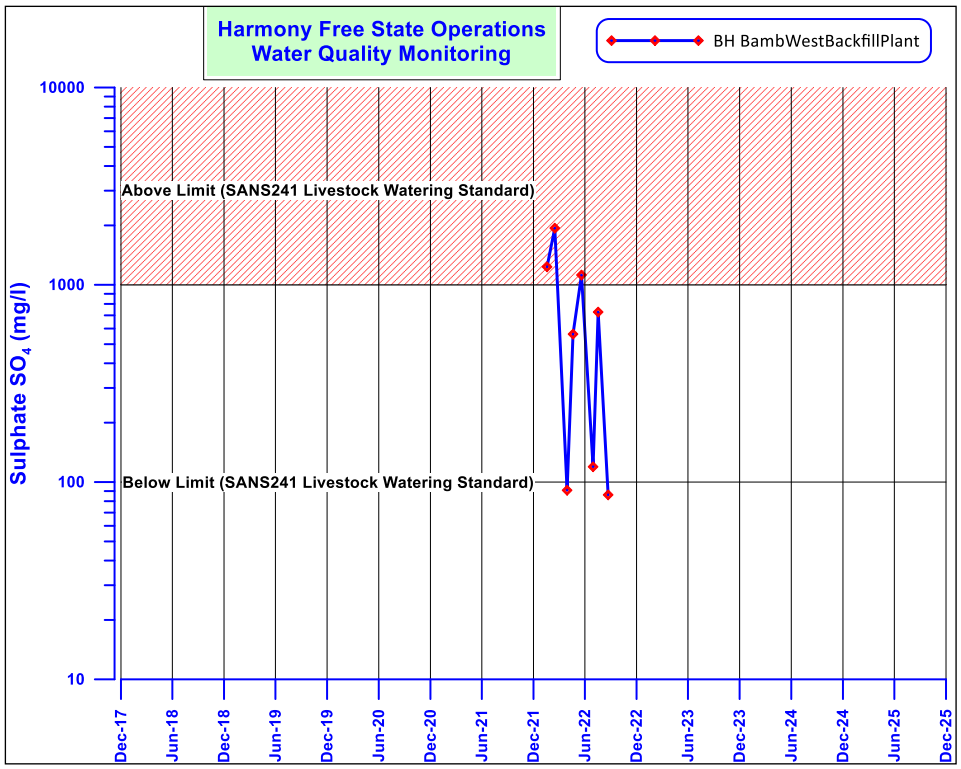

Harmony Free State Operations
Water Quality Monitoring
ESW07
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

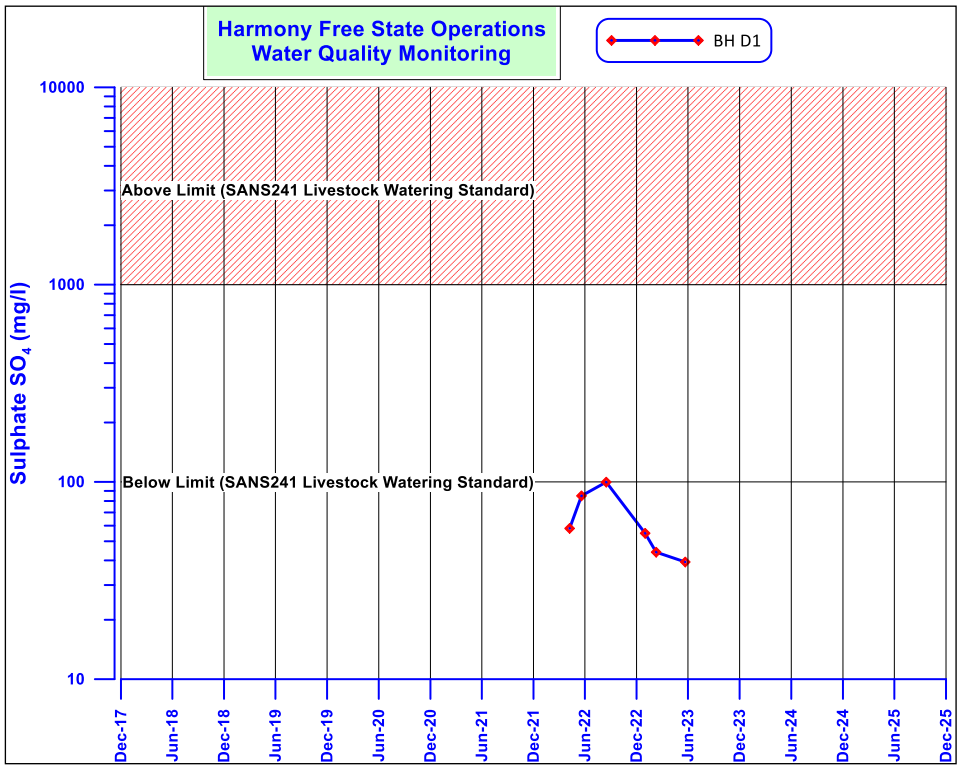
Appendix IV
Welkom Harmony – Observed Sulphate Concentrations at Monitoring Boreholes

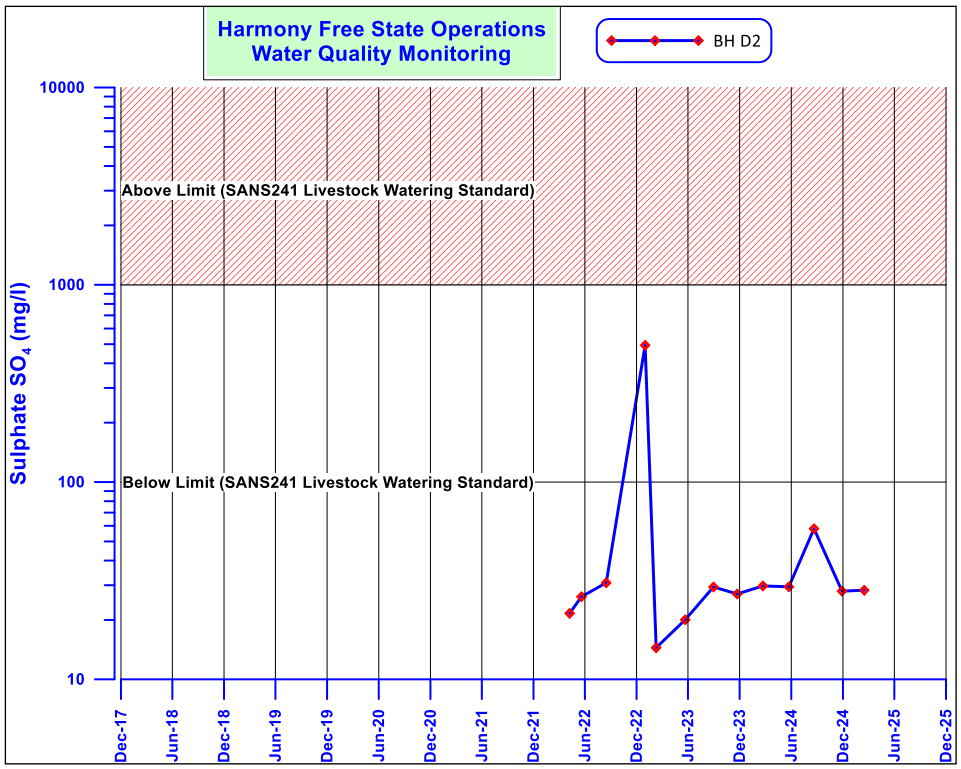

Harmony Free State Operations
Water Quality Monitoring
B2N1
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

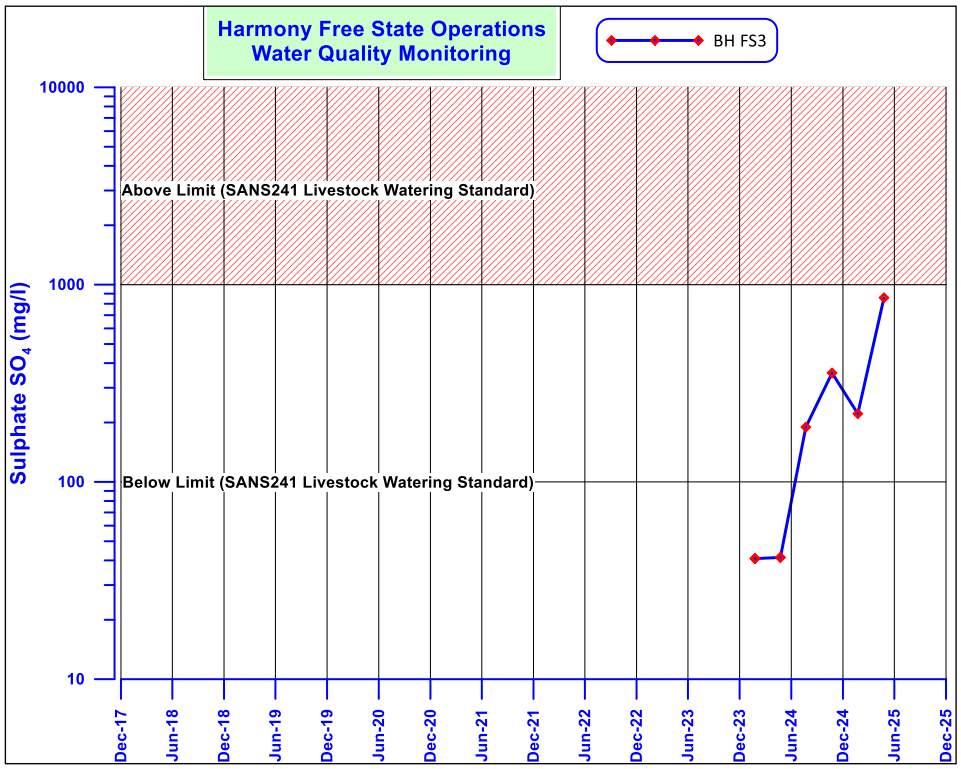

Harmony Free State Operations
Water Quality Monitoring
BH A7
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

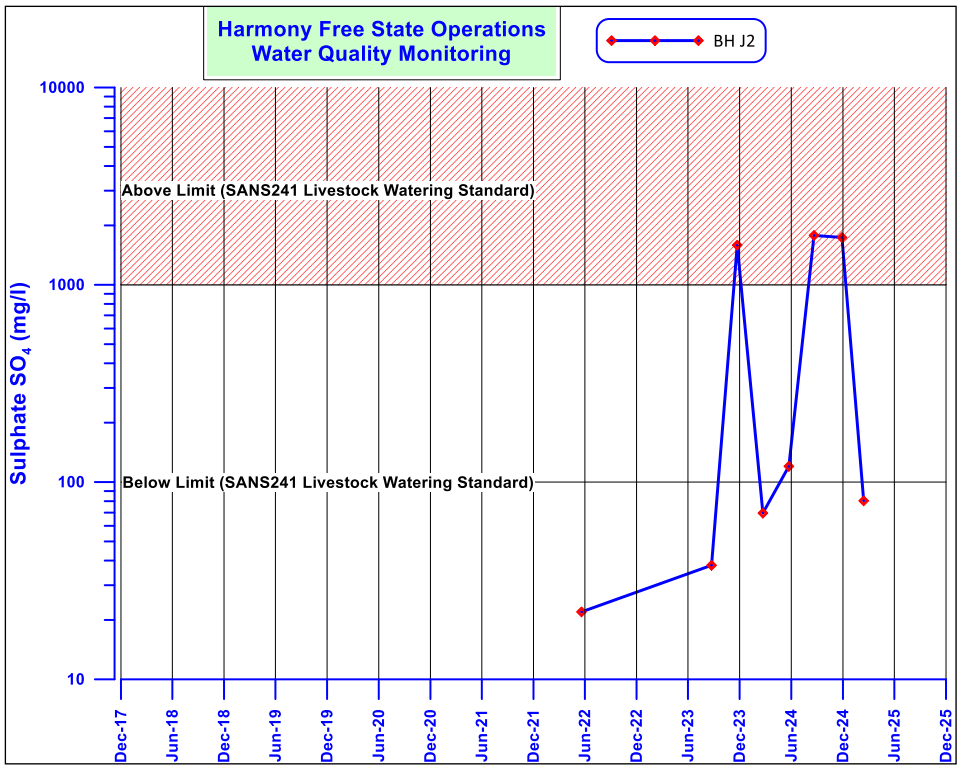

Harmony Free State Operations
Water Quality Monitoring
BH B41S
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

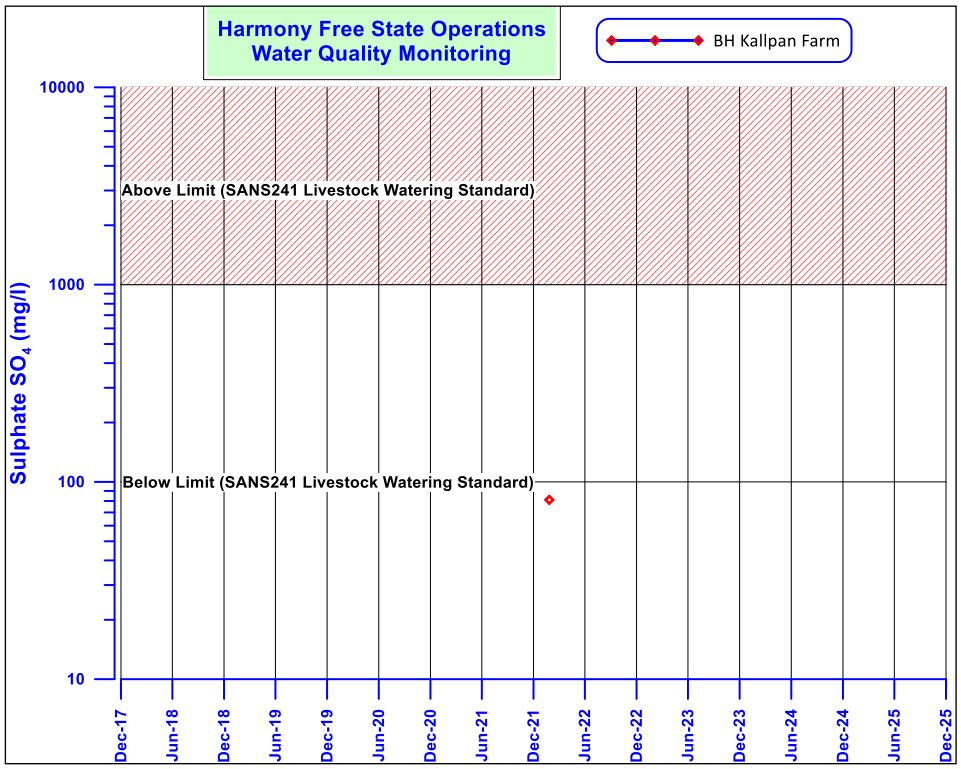

Harmony Free State Operations
Water Quality Monitoring
BH BambWestBackfillPlant
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

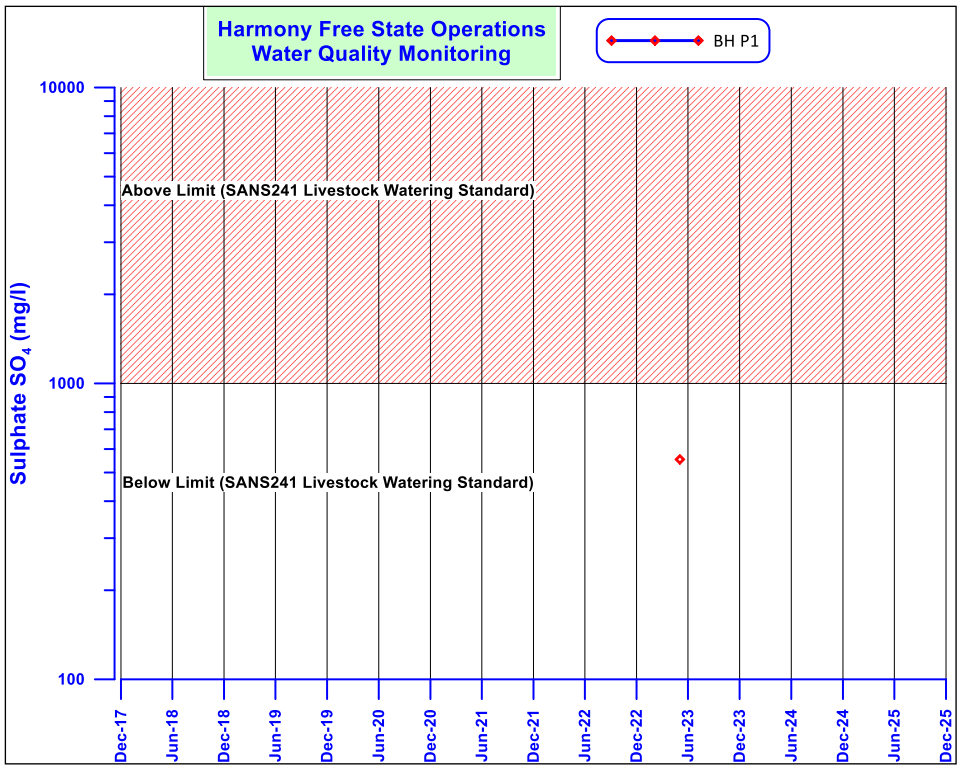

Harmony Free State Operations
Water Quality Monitoring
BH D1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

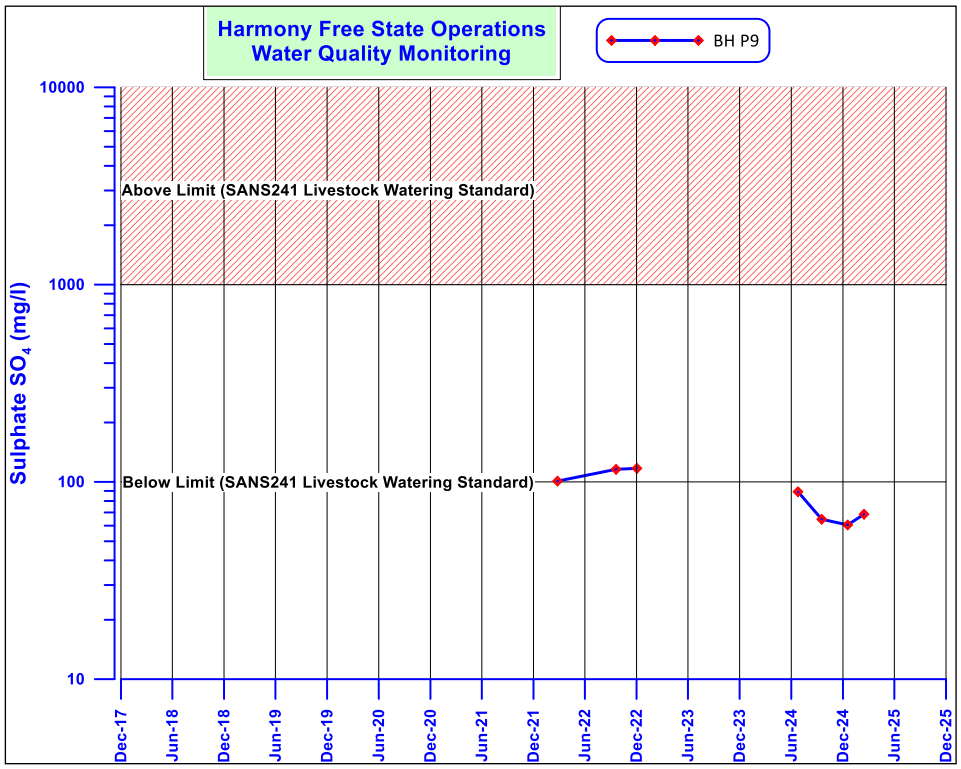

Harmony Free State Operations
Water Quality Monitoring
BH D2
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

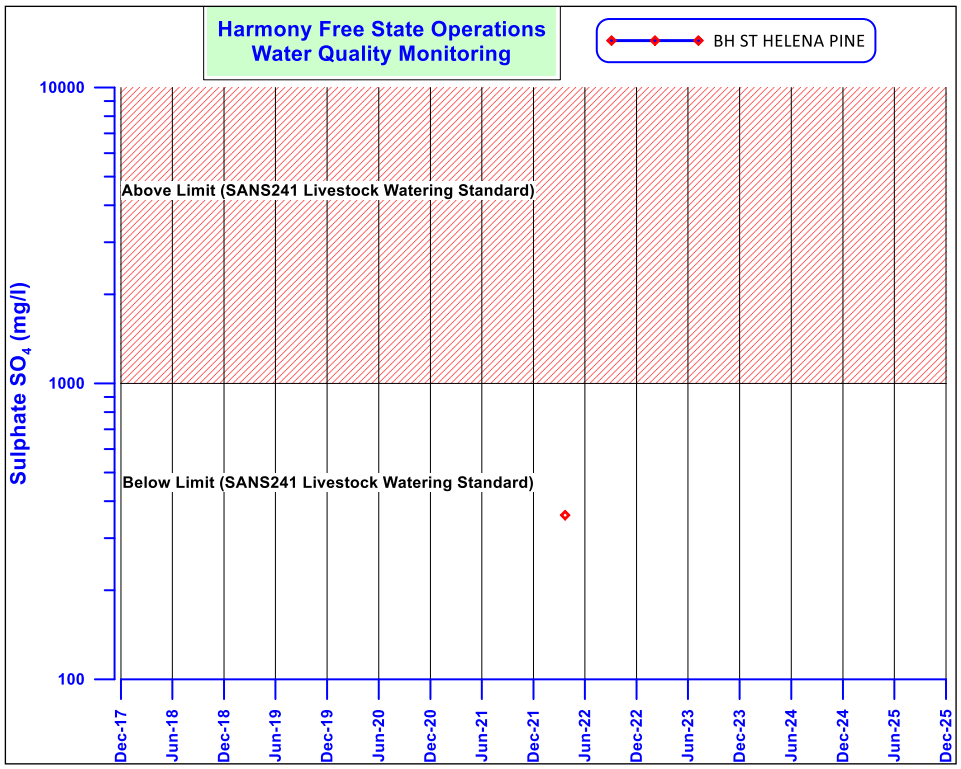

Harmony Free State Operations
Water Quality Monitoring
BH FS3
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

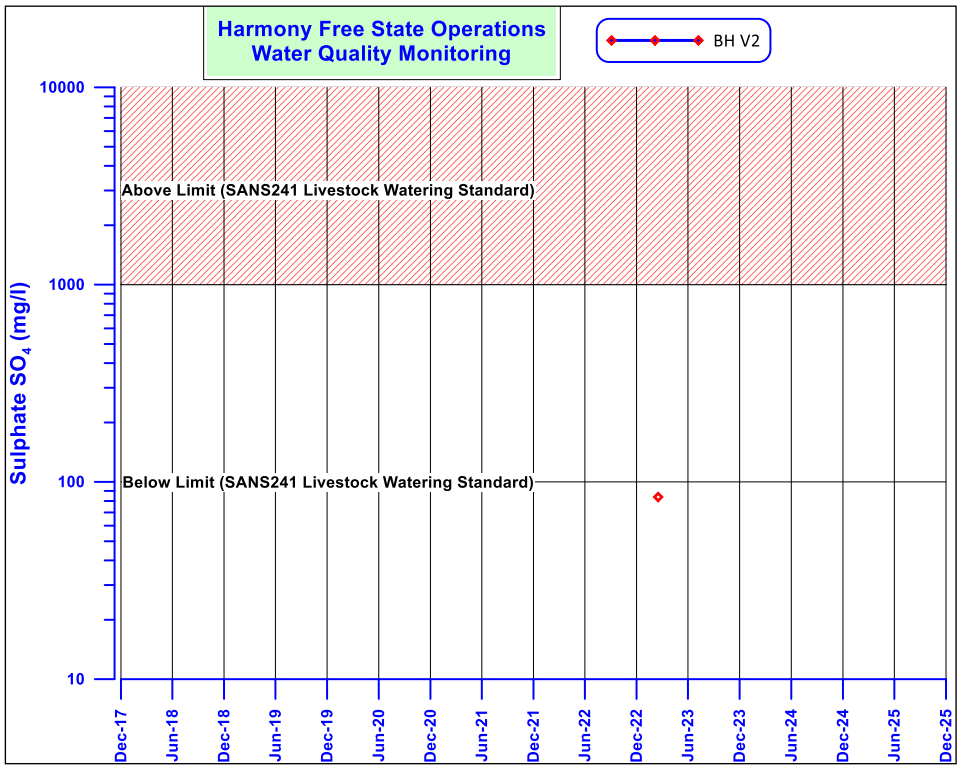

Harmony Free State Operations
Water Quality Monitoring
BH J2
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

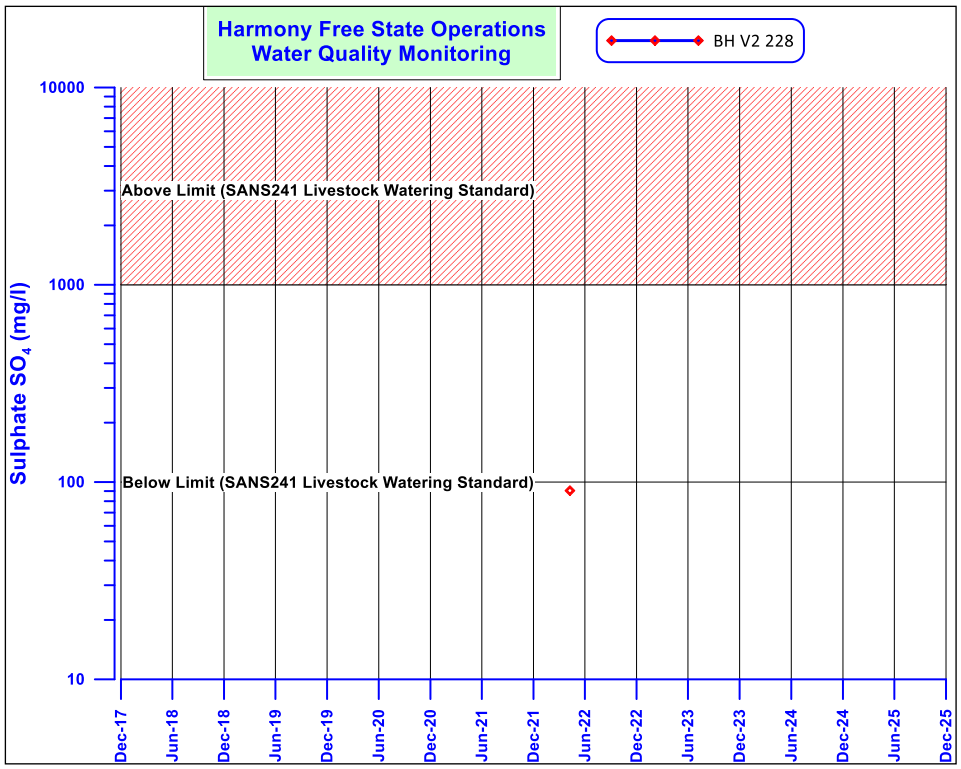

Harmony Free State Operations
Water Quality Monitoring
BH Kallpan Farm
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

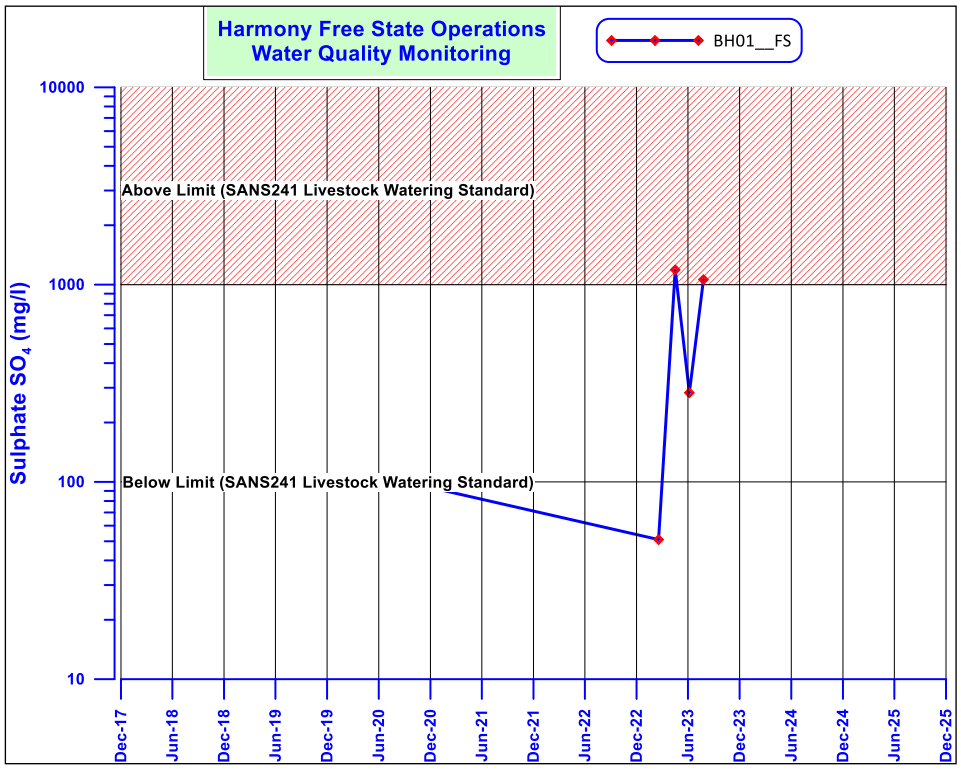

Harmony Free State Operations
Water Quality Monitoring
BH P1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

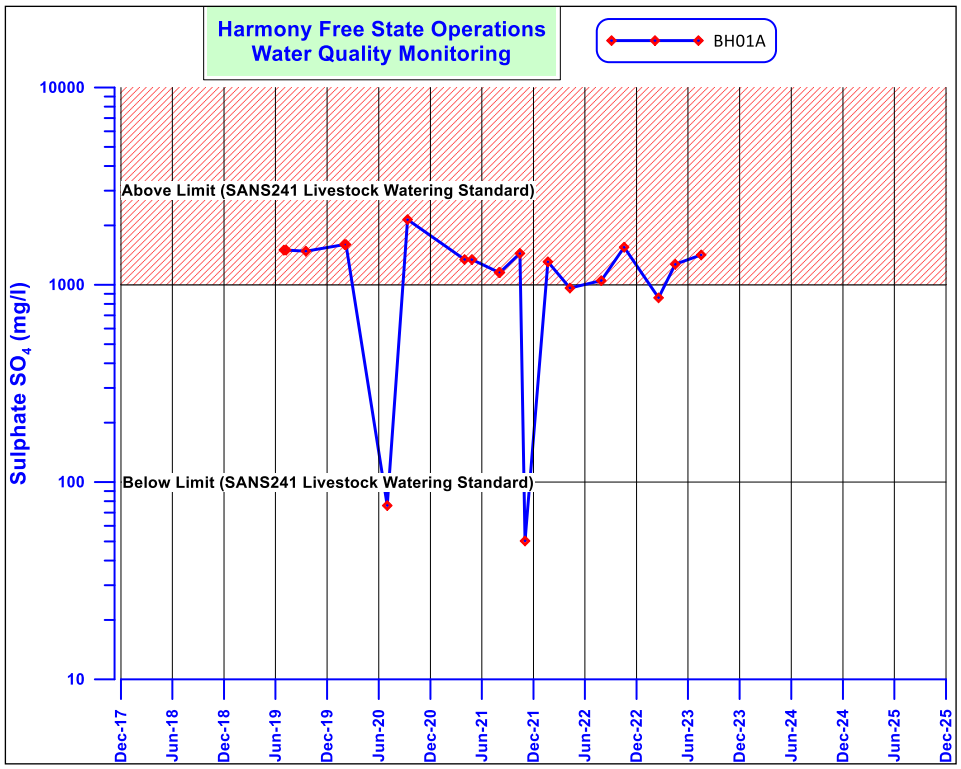

Harmony Free State Operations
Water Quality Monitoring
BH P9
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

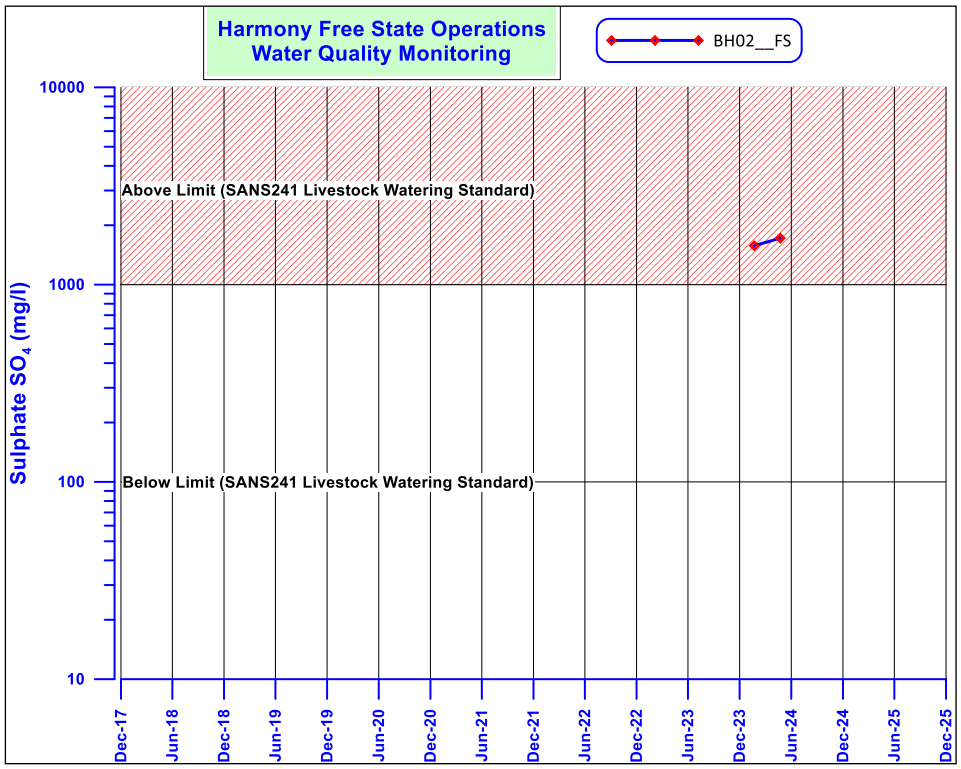

Harmony Free State Operations
Water Quality Monitoring
BH ST HELENA PINE
Sulphate SO_4 (mg/l)
10000
1000
100
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

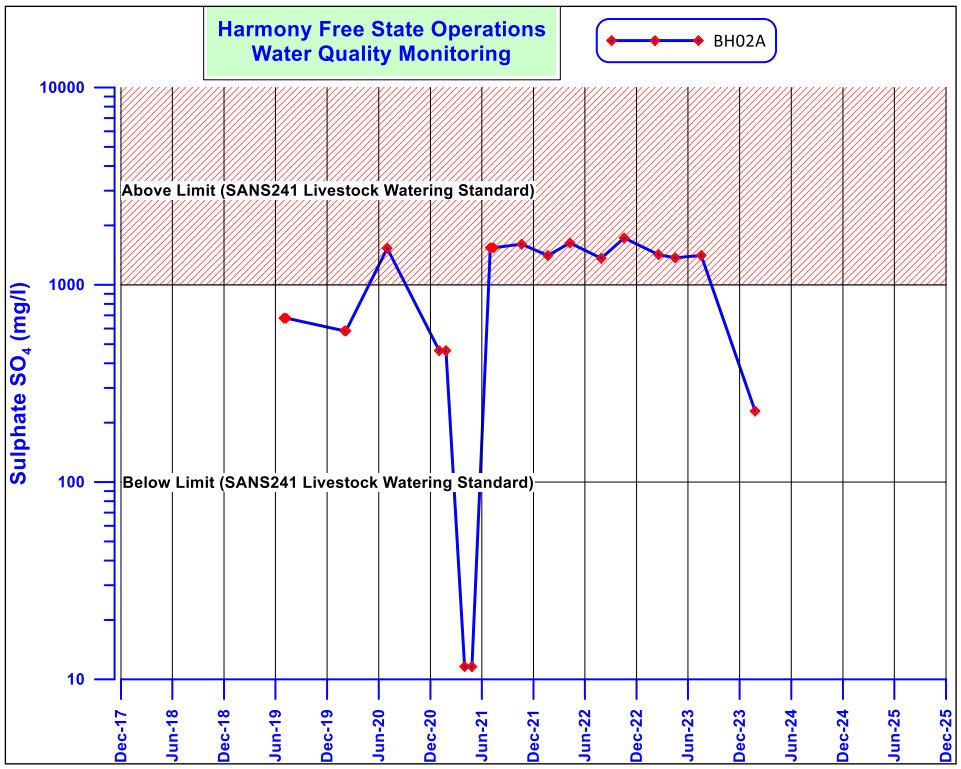

Harmony Free State Operations
Water Quality Monitoring
BH V2
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

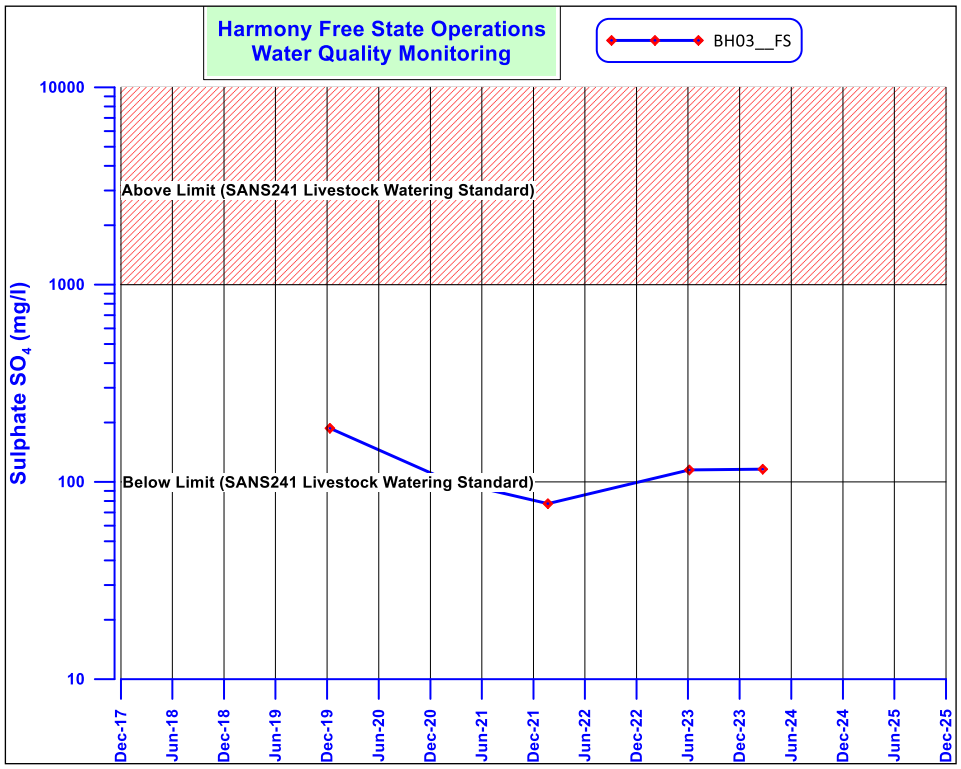

Harmony Free State Operations
Water Quality Monitoring
BH V2 228
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

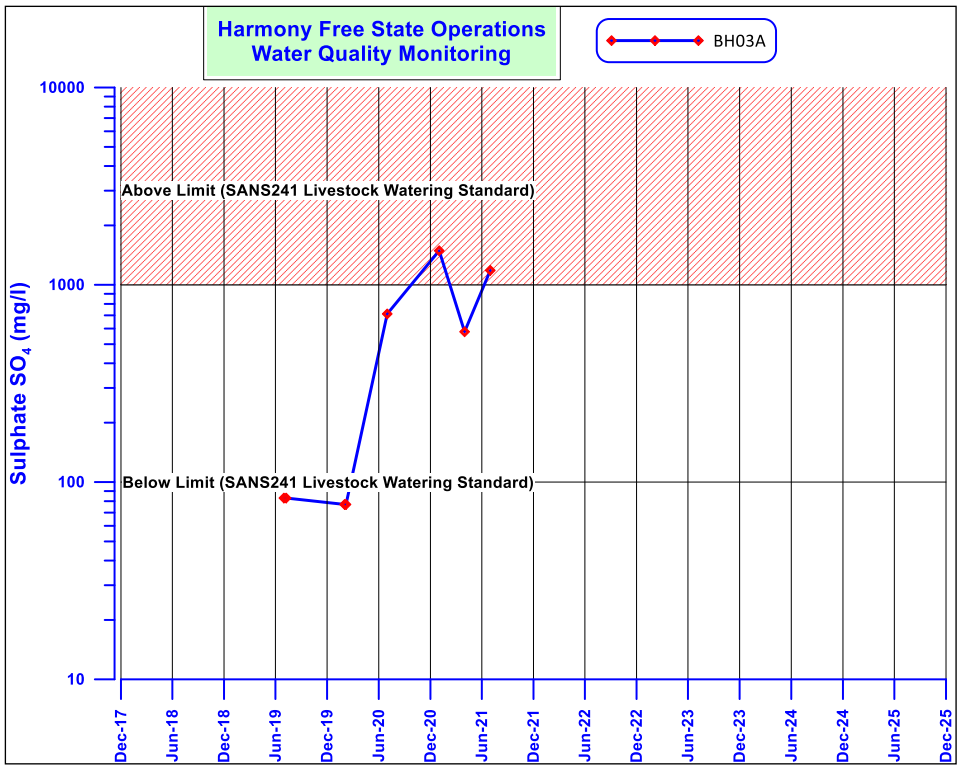

Harmony Free State Operations
Water Quality Monitoring
BH01__FS
Sulphate SO4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

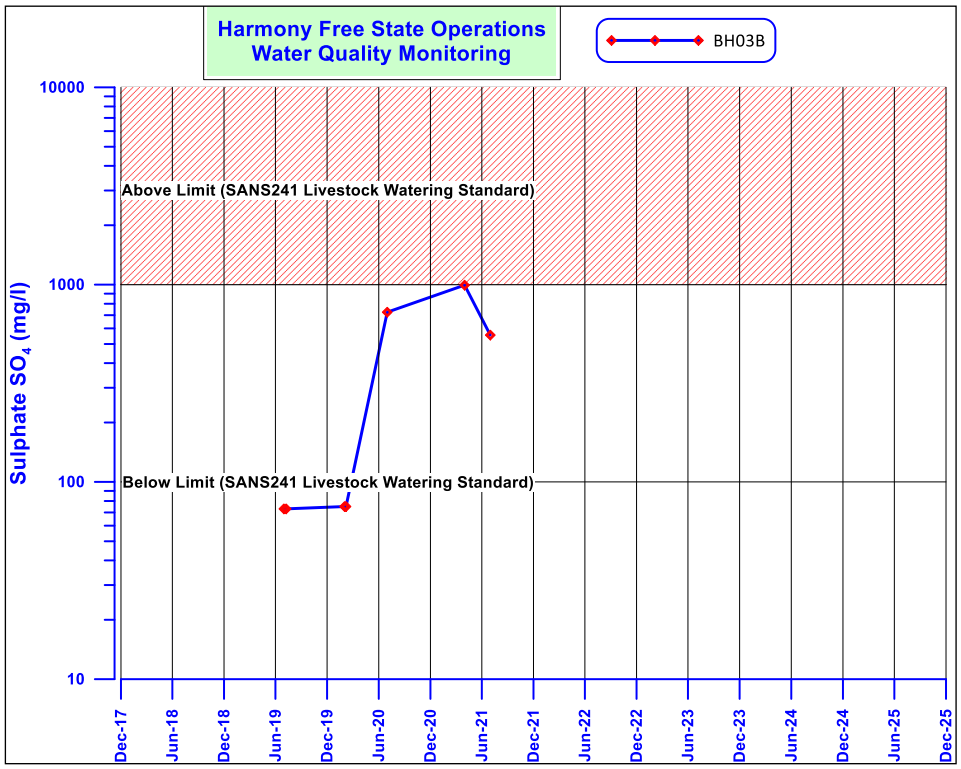

Harmony Free State Operations
Water Quality Monitoring
BH01A
Sulphate SO4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

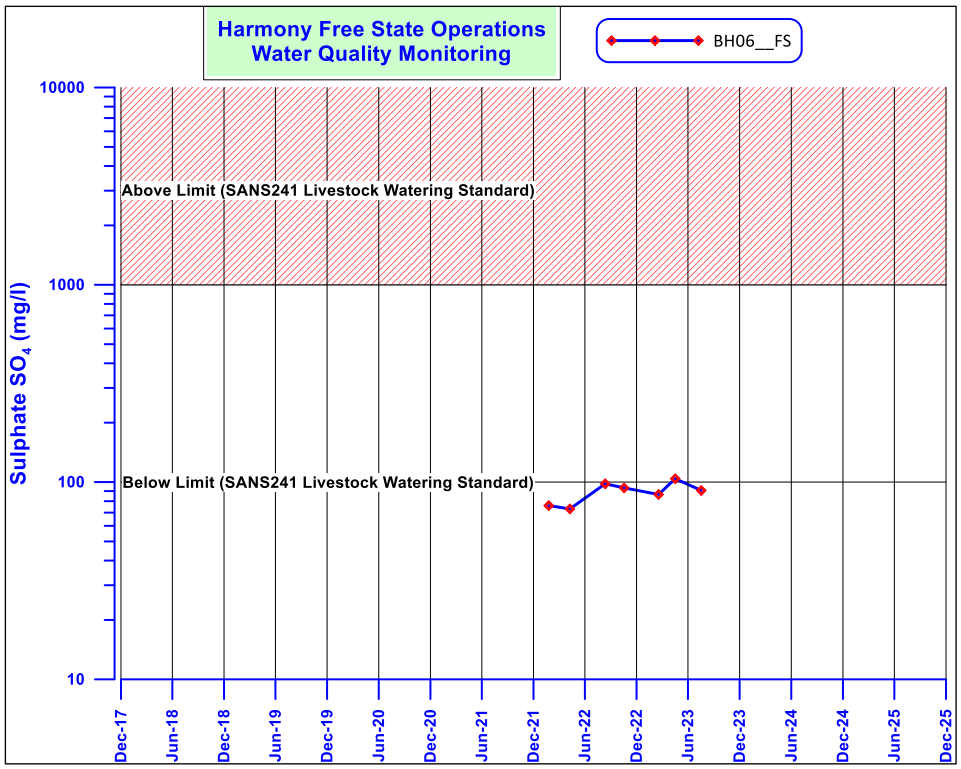

Harmony Free State Operations
Water Quality Monitoring
BH02__FS
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

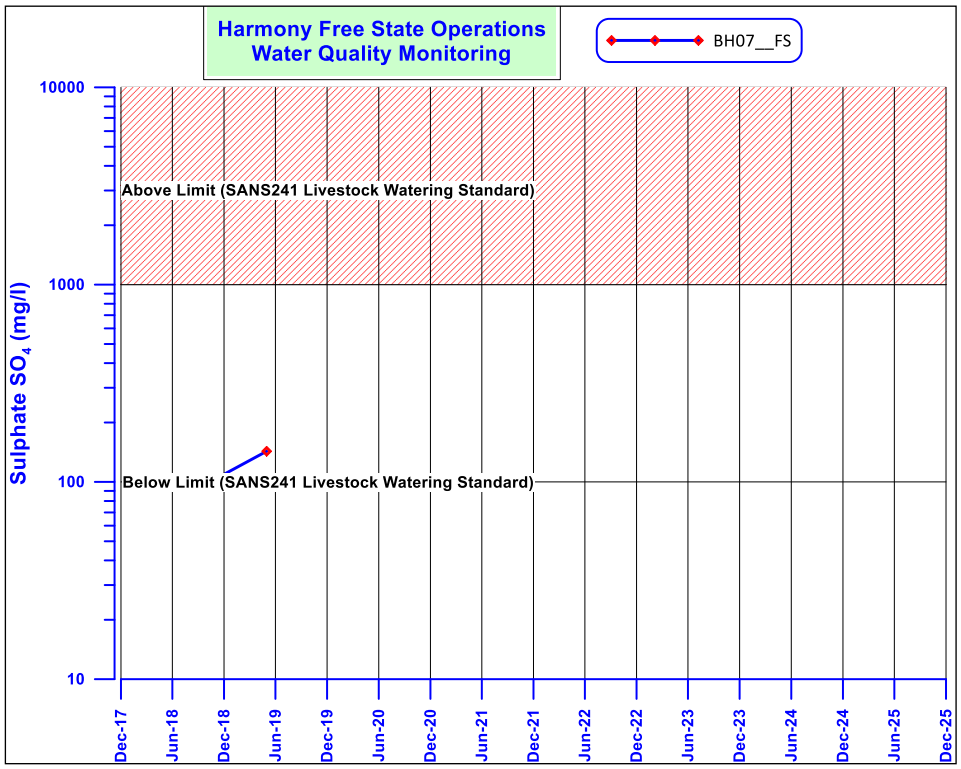

Harmony Free State Operations
Water Quality Monitoring
BH02A
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

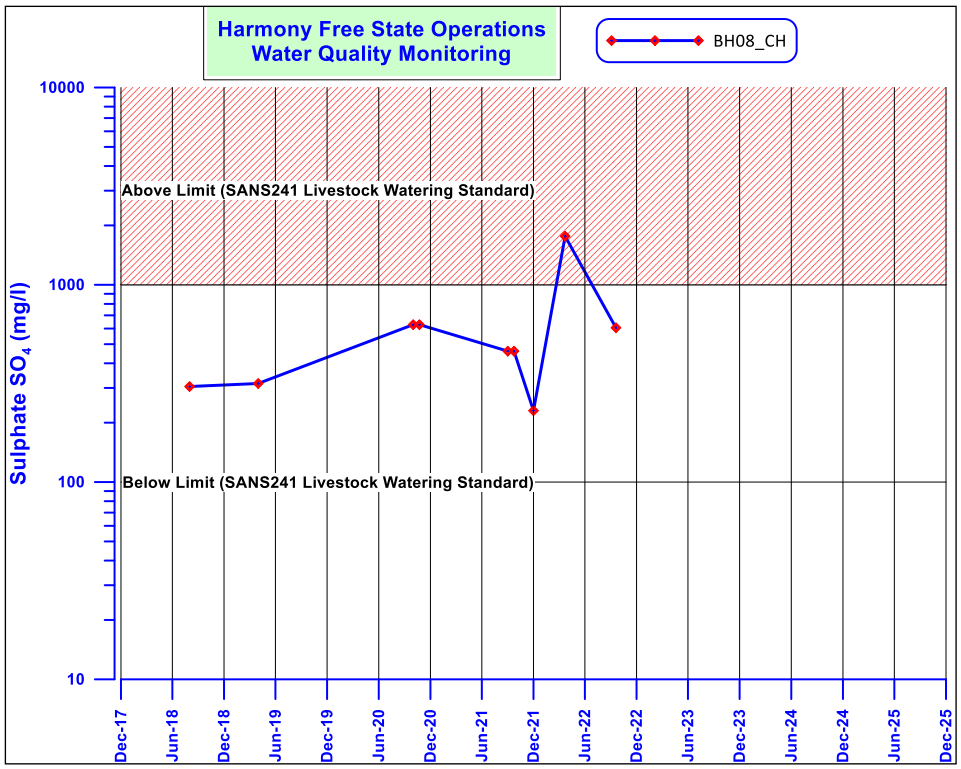

Harmony Free State Operations
Water Quality Monitoring
BH03__FS
Sulphate SO4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

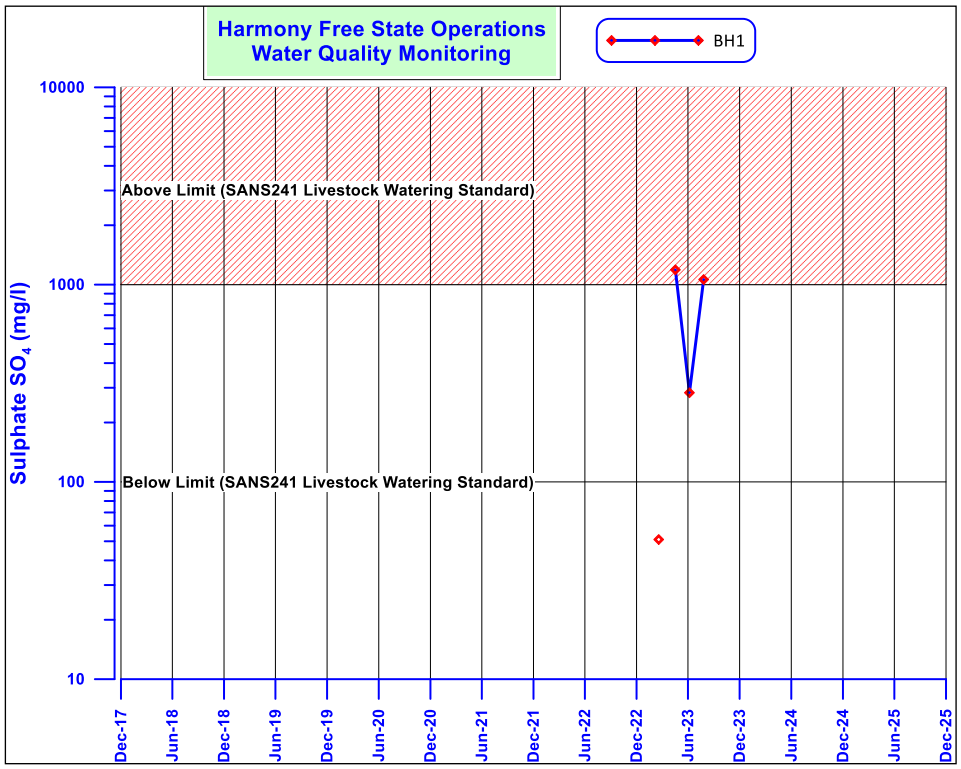

Harmony Free State Operations
Water Quality Monitoring
BH03A
Sulphate SO4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

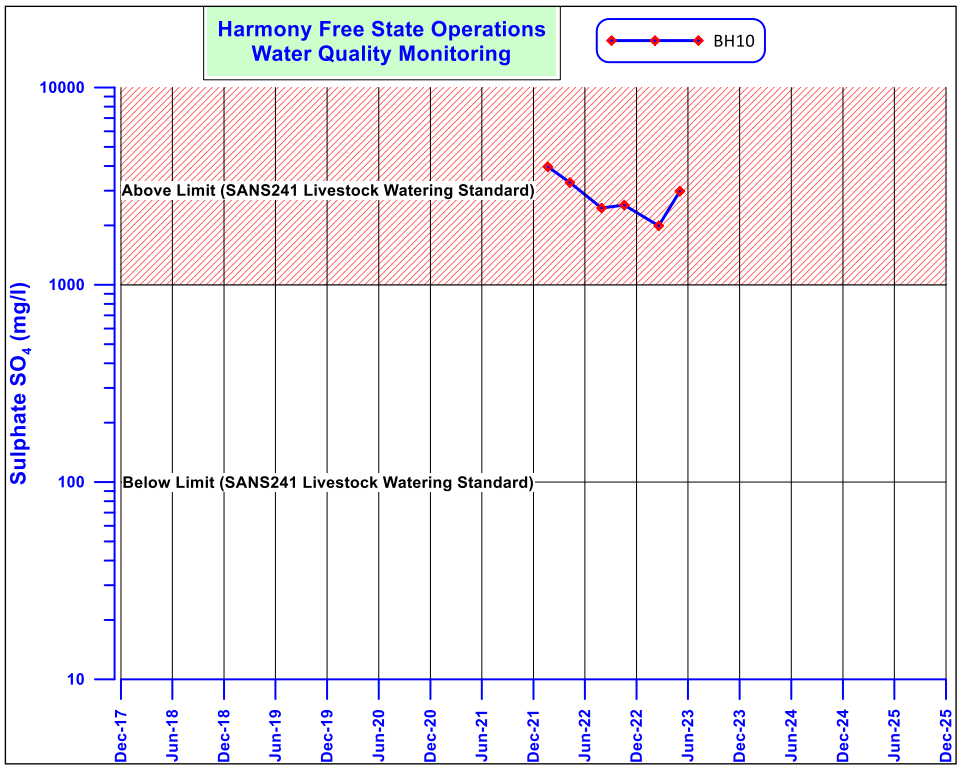

Harmony Free State Operations
Water Quality Monitoring
BH03B
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

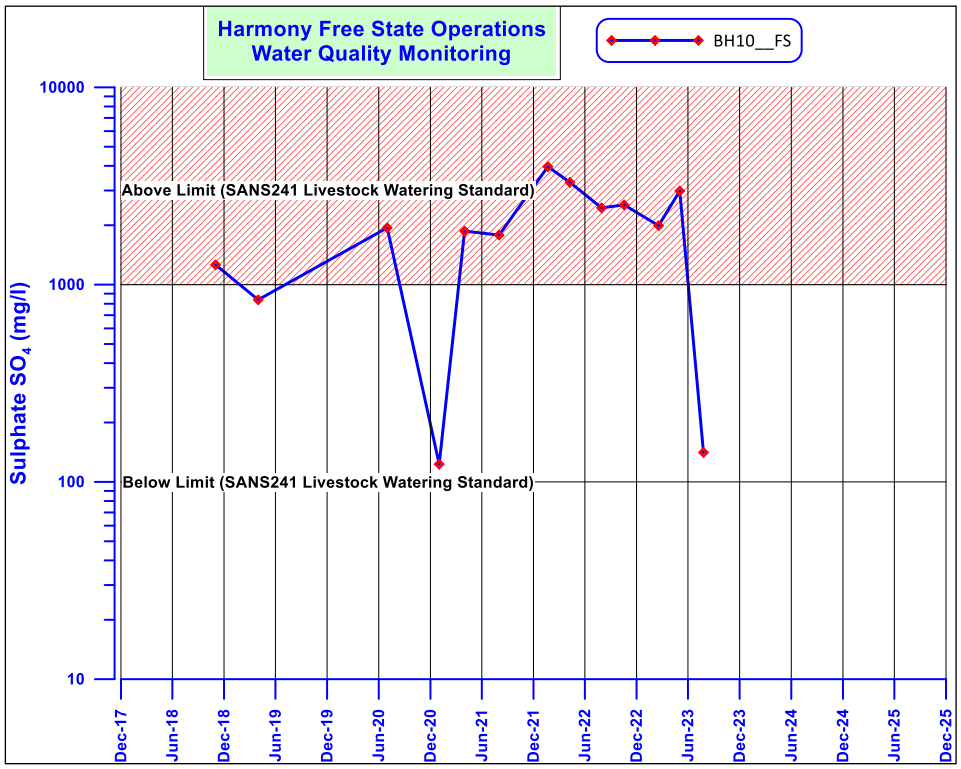

Harmony Free State Operations
Water Quality Monitoring
BH06__FS
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

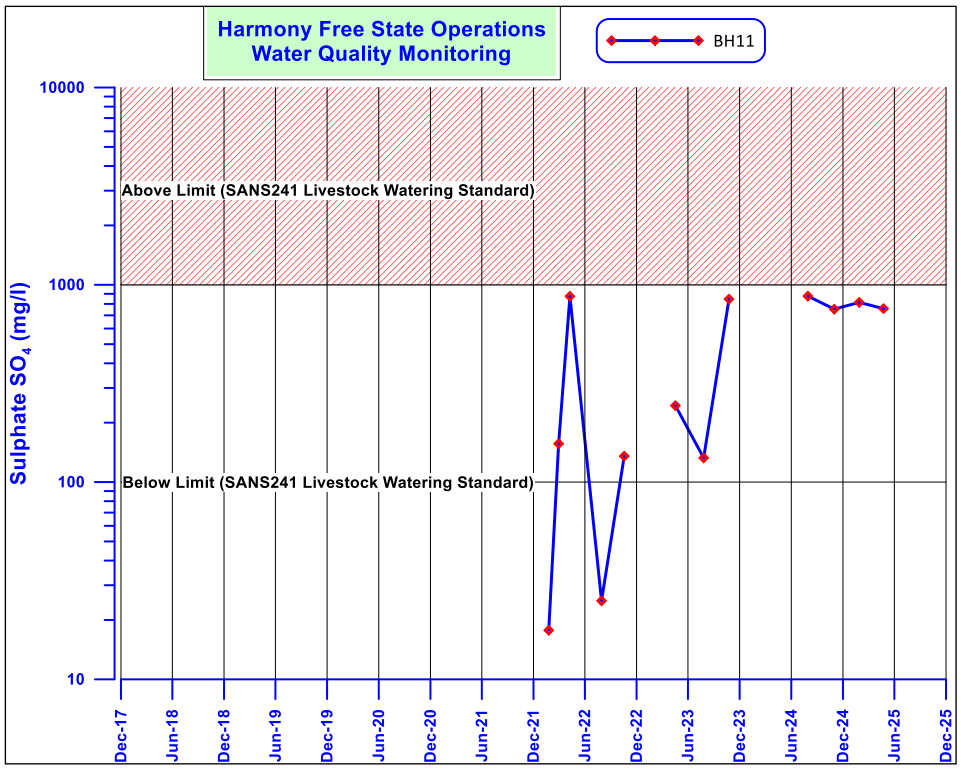

Harmony Free State Operations
Water Quality Monitoring
BH07__FS
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

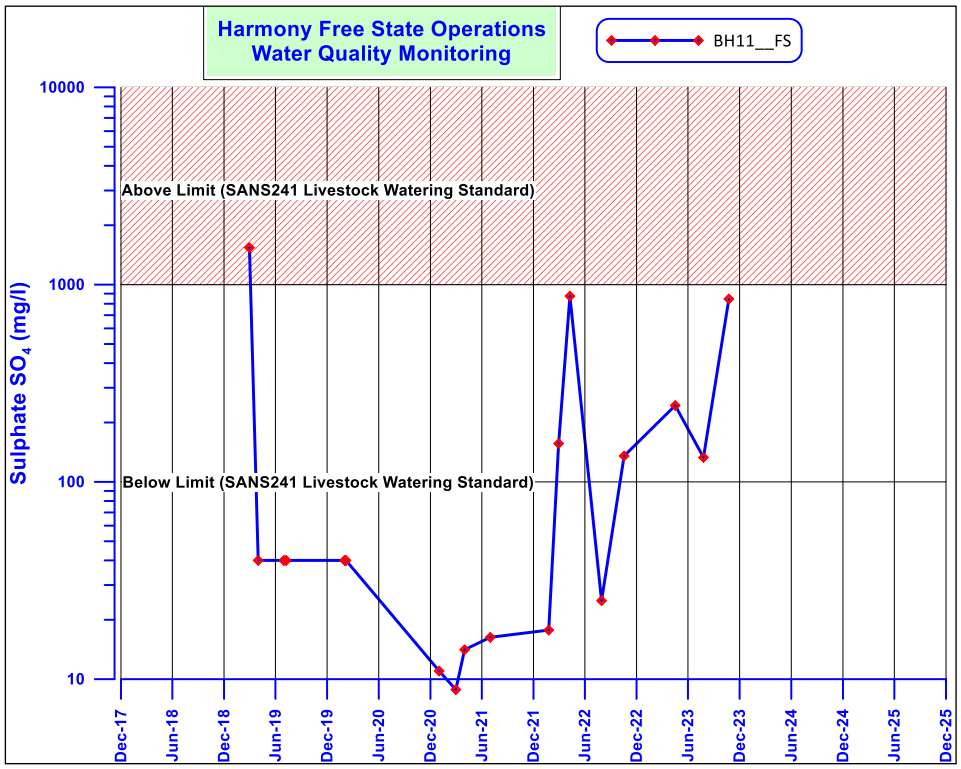

Harmony Free State Operations
Water Quality Monitoring
BH08_CH
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

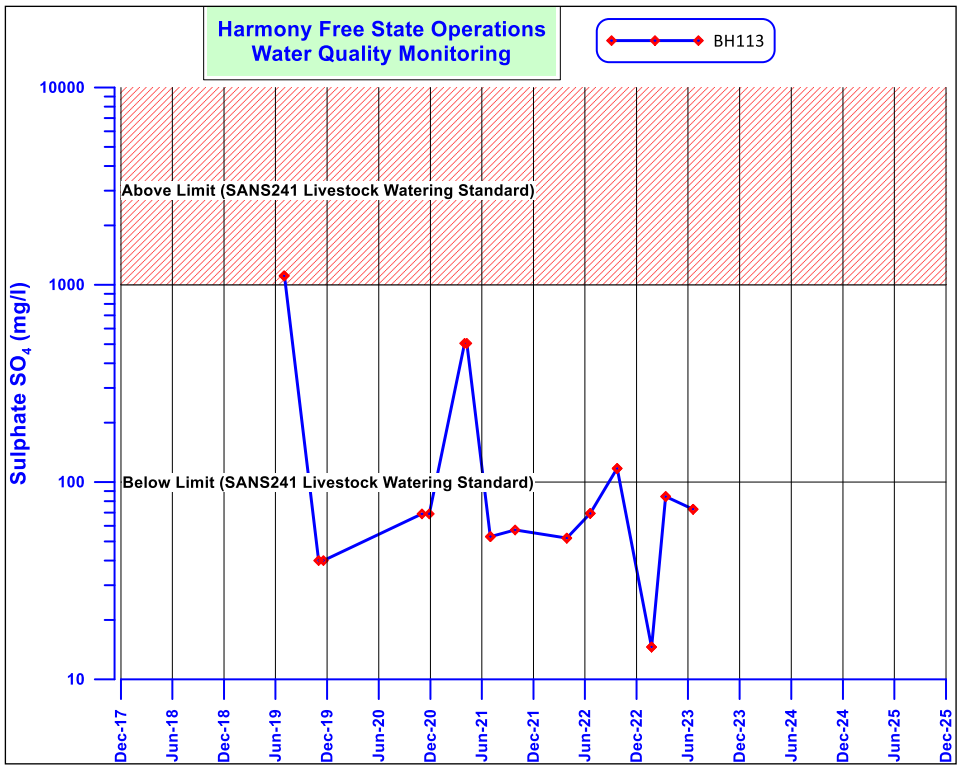

Harmony Free State Operations
Water Quality Monitoring
BH1
Sulphate SO4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

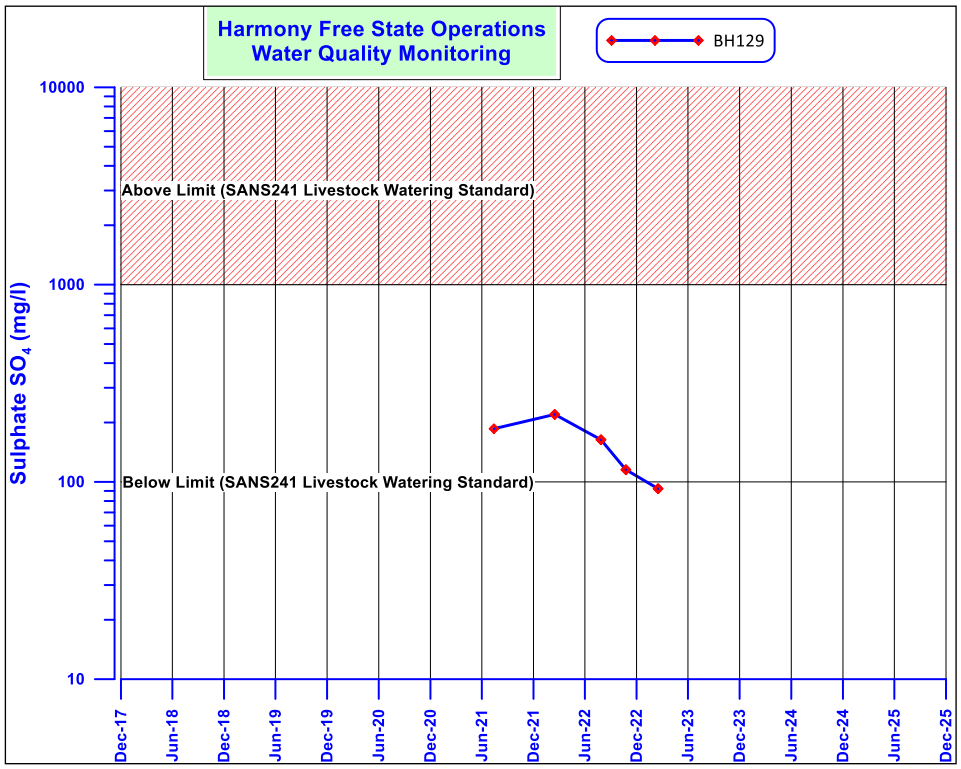

Harmony Free State Operations
Water Quality Monitoring
BH10
Sulphate SO4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

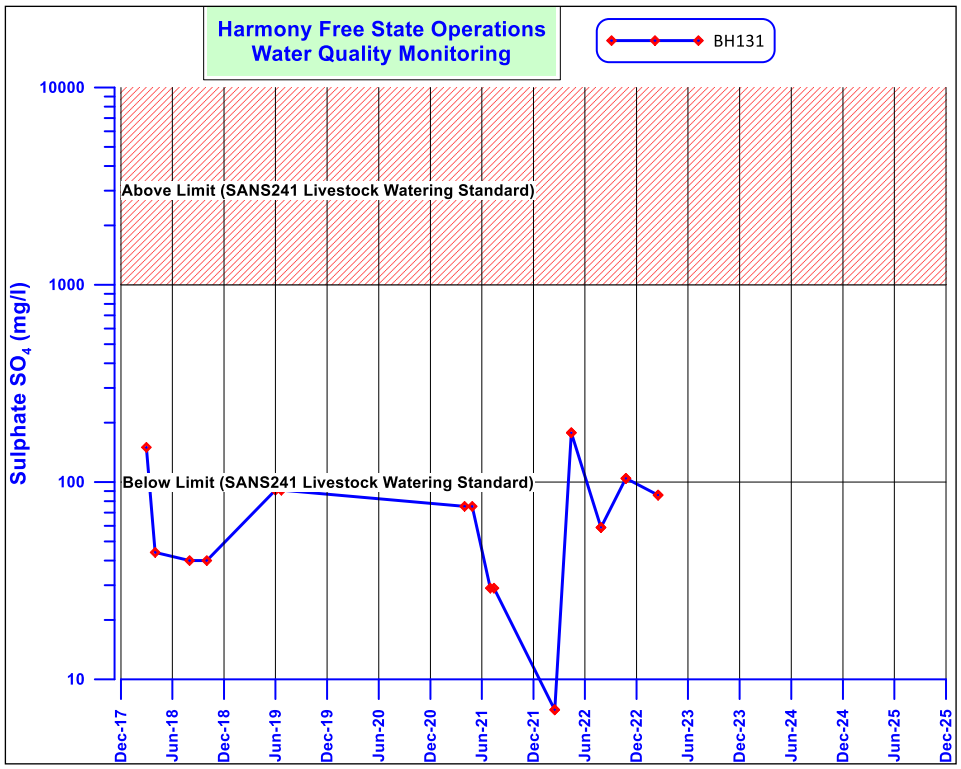

Harmony Free State Operations
Water Quality Monitoring
BH10__FS
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

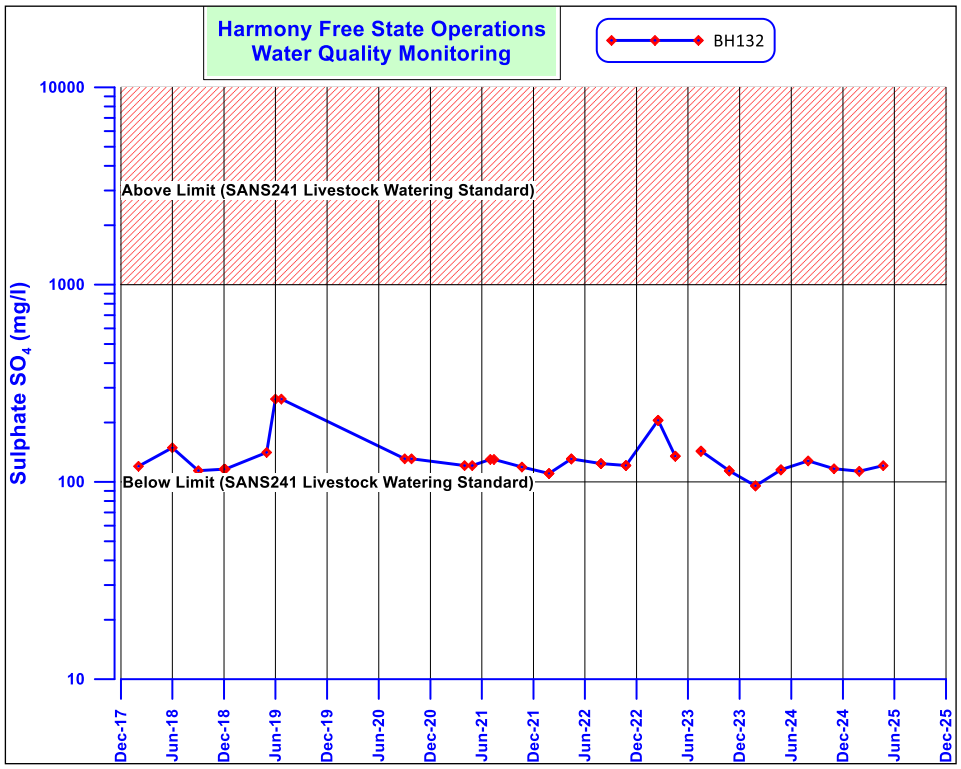

Harmony Free State Operations
Water Quality Monitoring
BH11
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

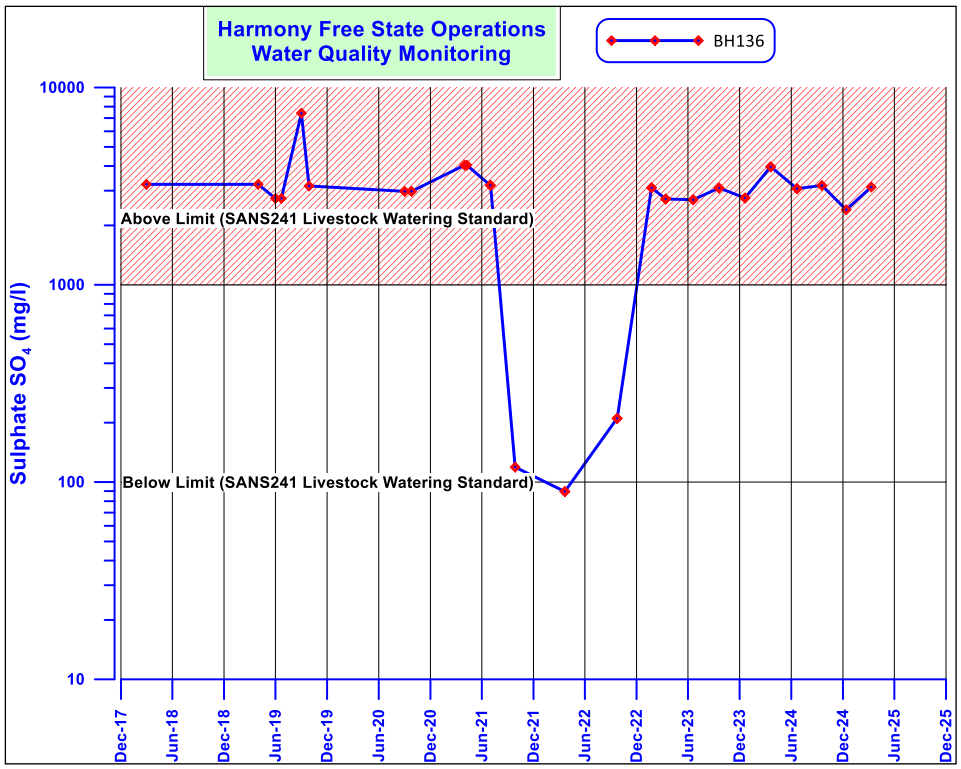

Harmony Free State Operations
Water Quality Monitoring
BH11__FS
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

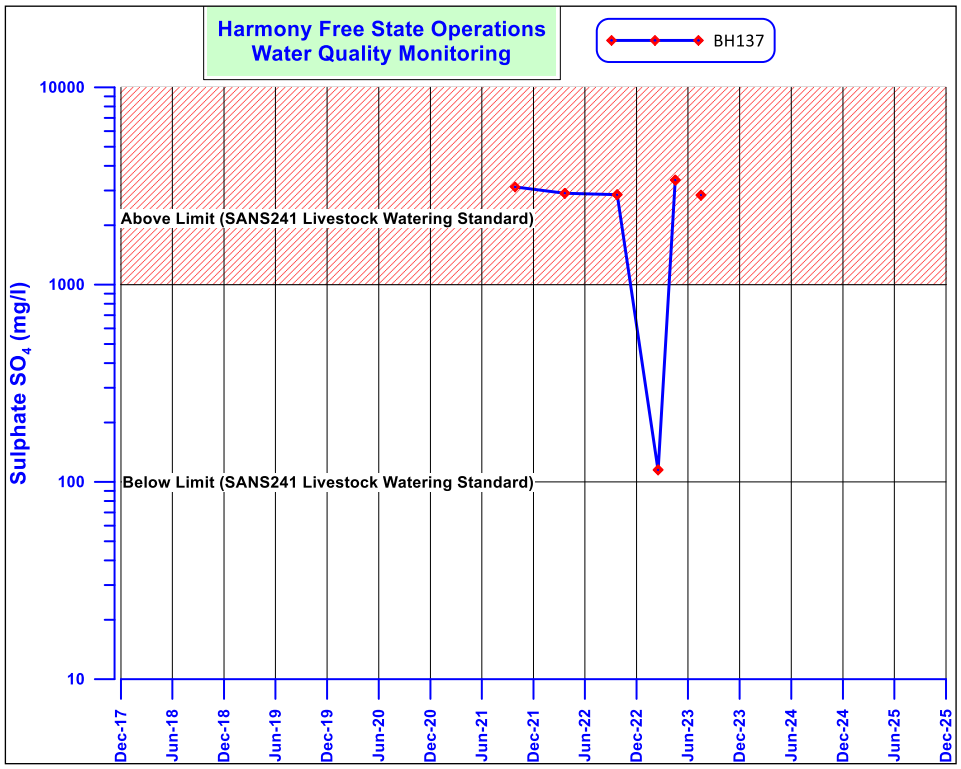

Harmony Free State Operations
Water Quality Monitoring
BH113
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

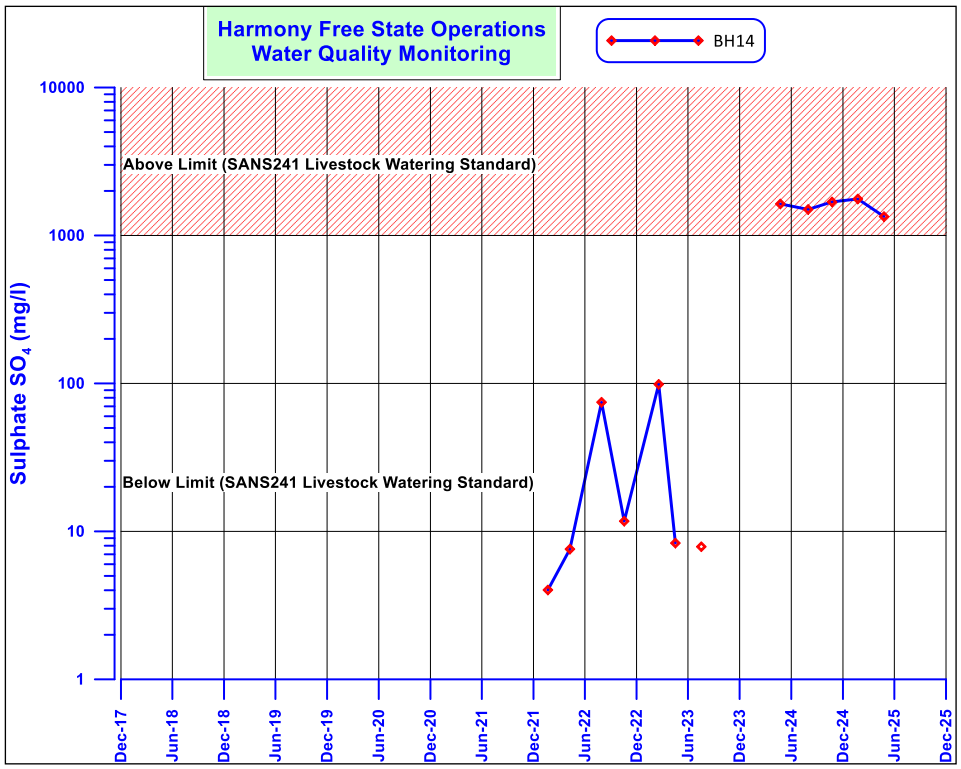

Harmony Free State Operations
Water Quality Monitoring
BH129
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

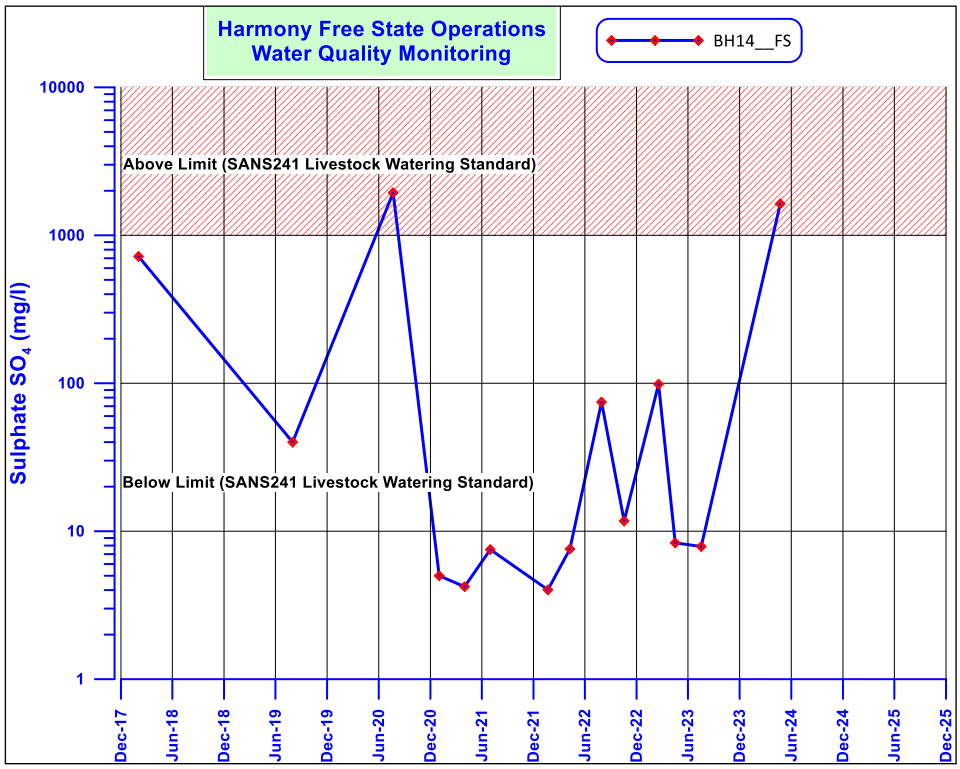

Harmony Free State Operations
Water Quality Monitoring
BH131
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

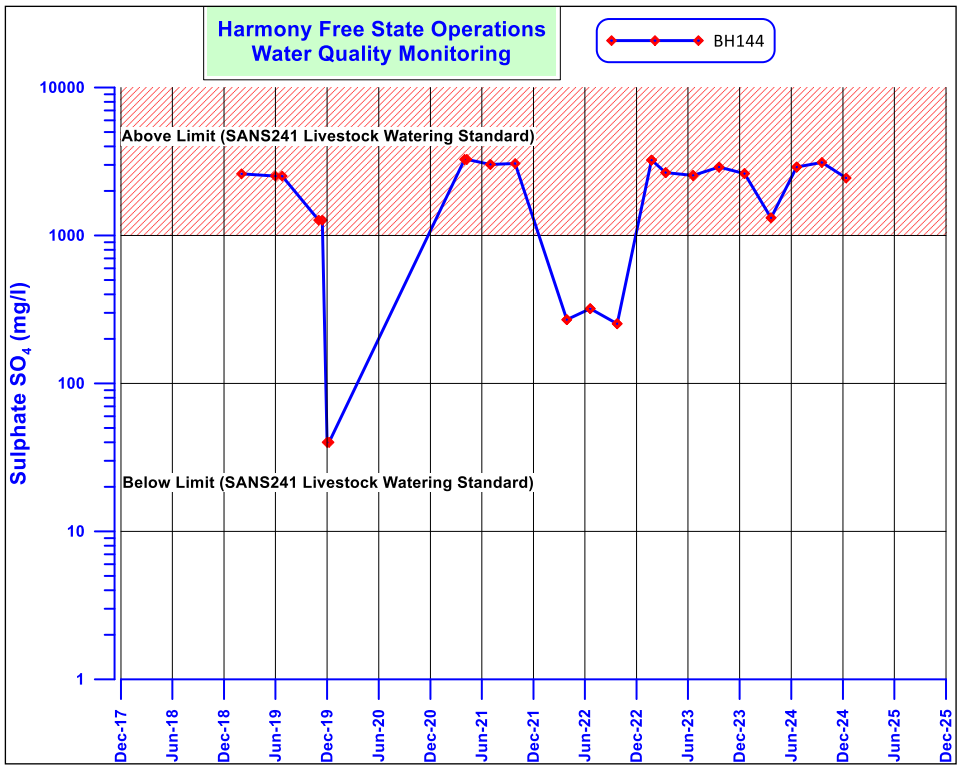

Harmony Free State Operations
Water Quality Monitoring
BH132
Sulphate SO4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

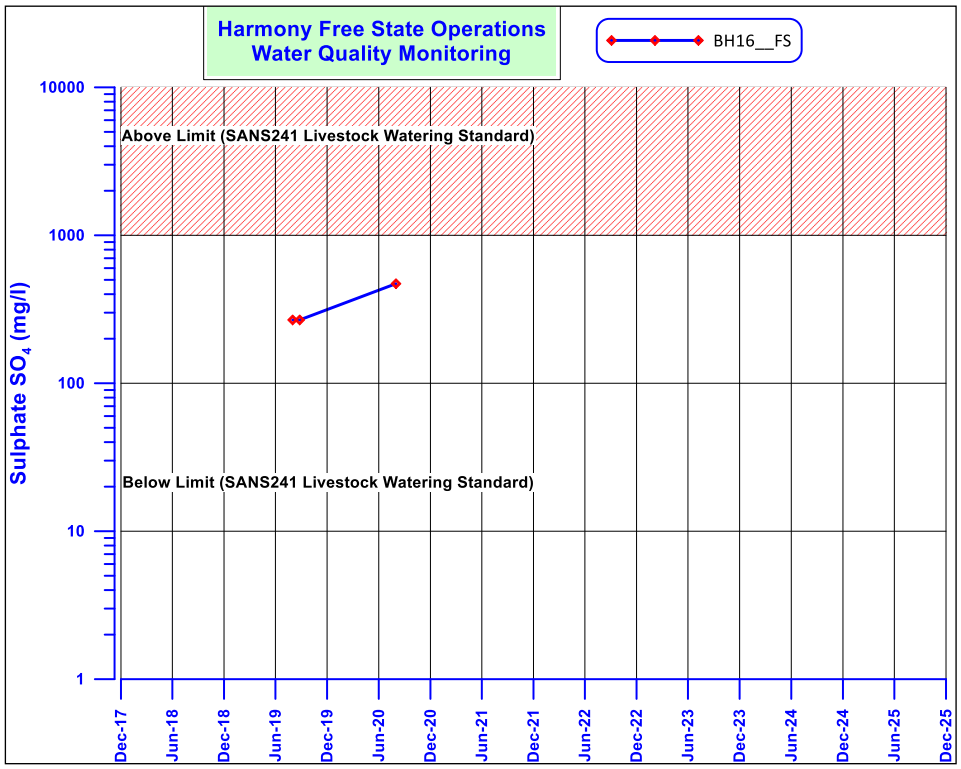

Harmony Free State Operations
Water Quality Monitoring
BH136
Sulphate SO4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

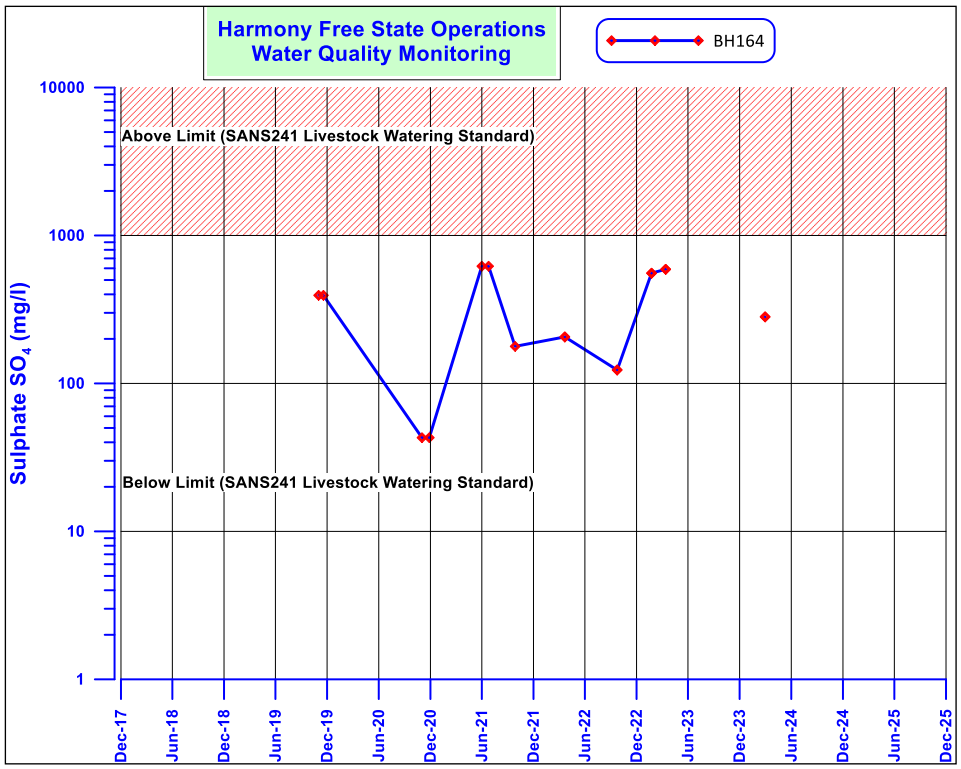

Harmony Free State Operations
Water Quality Monitoring
BH137
Sulphate SO_4 (mg/l)
10000
1000
100
10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

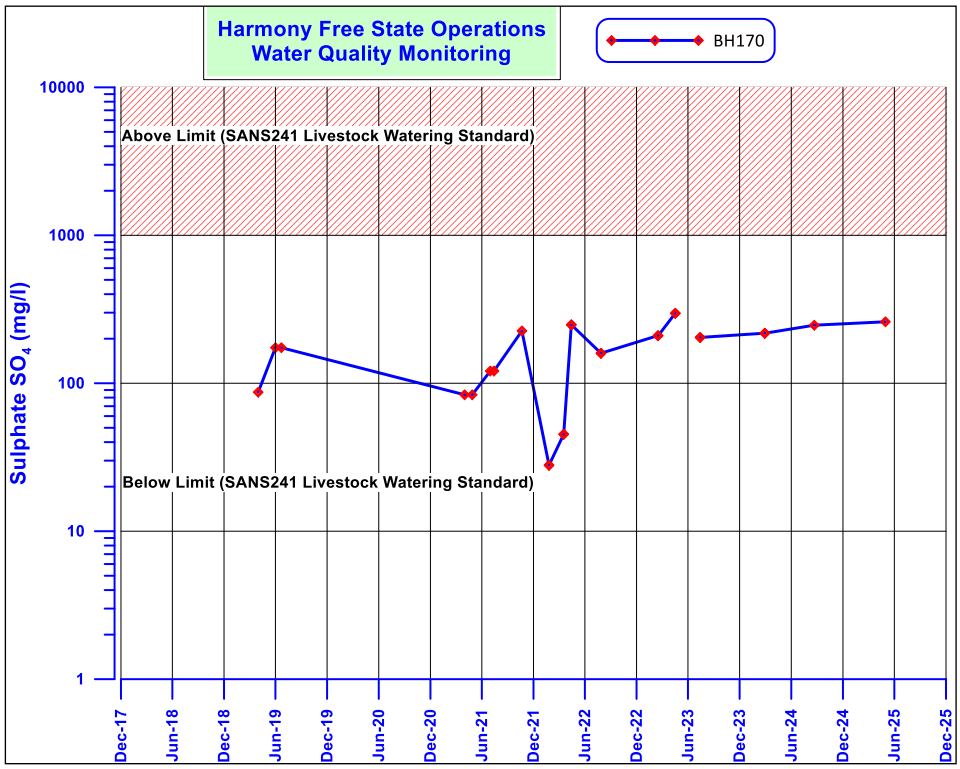

Harmony Free State Operations
Water Quality Monitoring
BH14
Sulphate SO_4 (mg/l)
10000
1000
100
10
1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

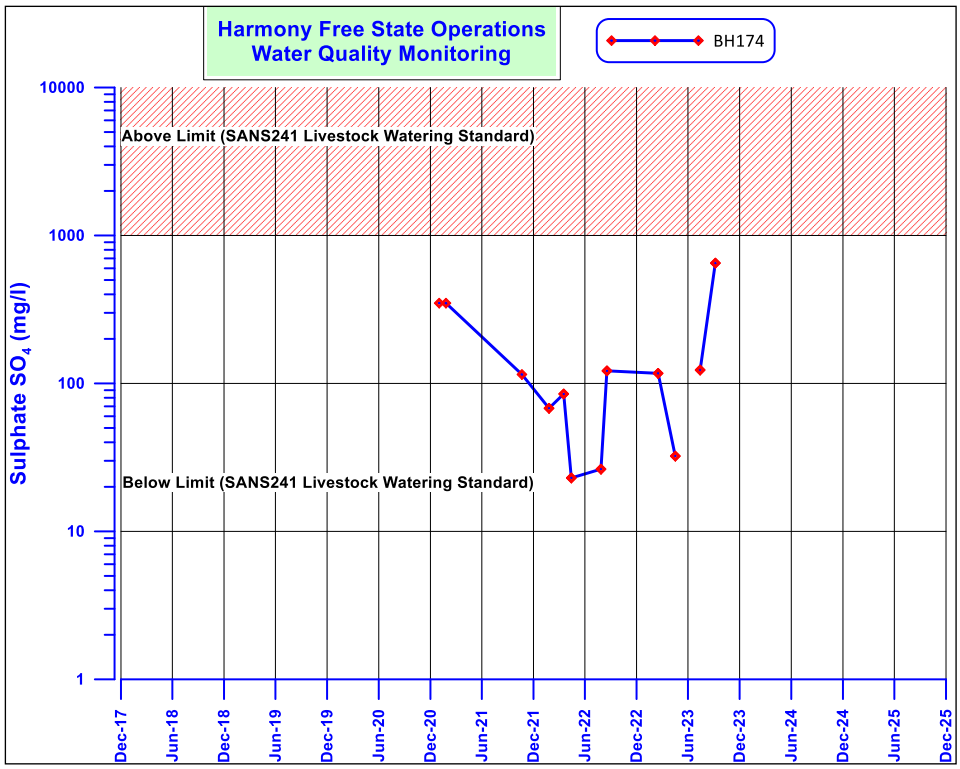

Harmony Free State Operations
Water Quality Monitoring
BH14__FS
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

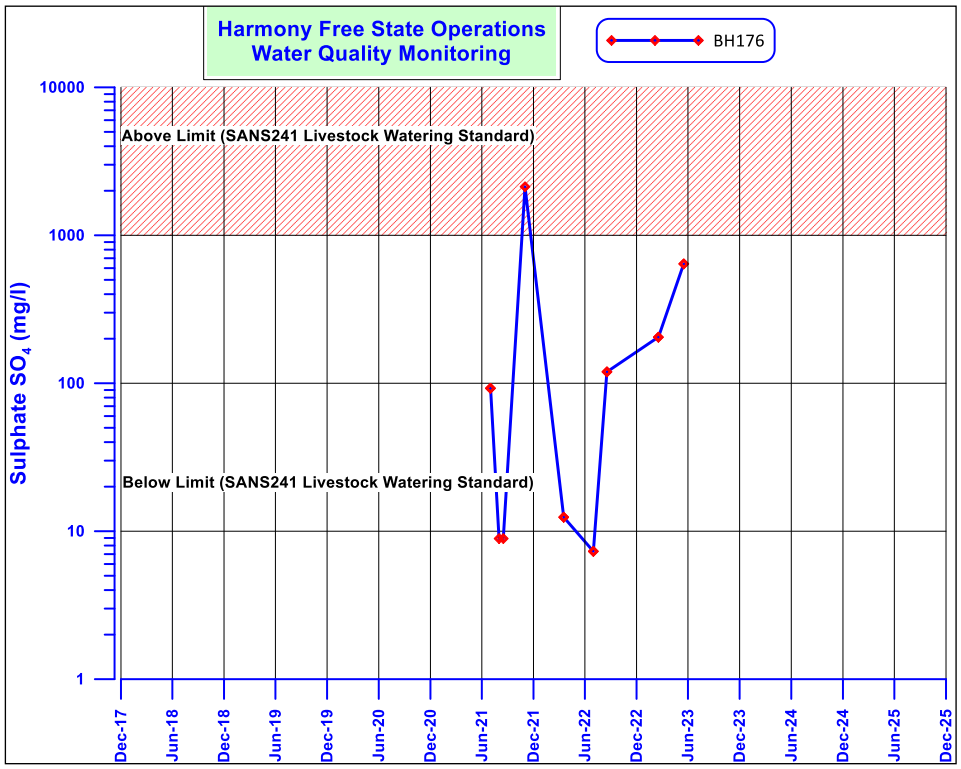

Harmony Free State Operations
Water Quality Monitoring
BH144
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

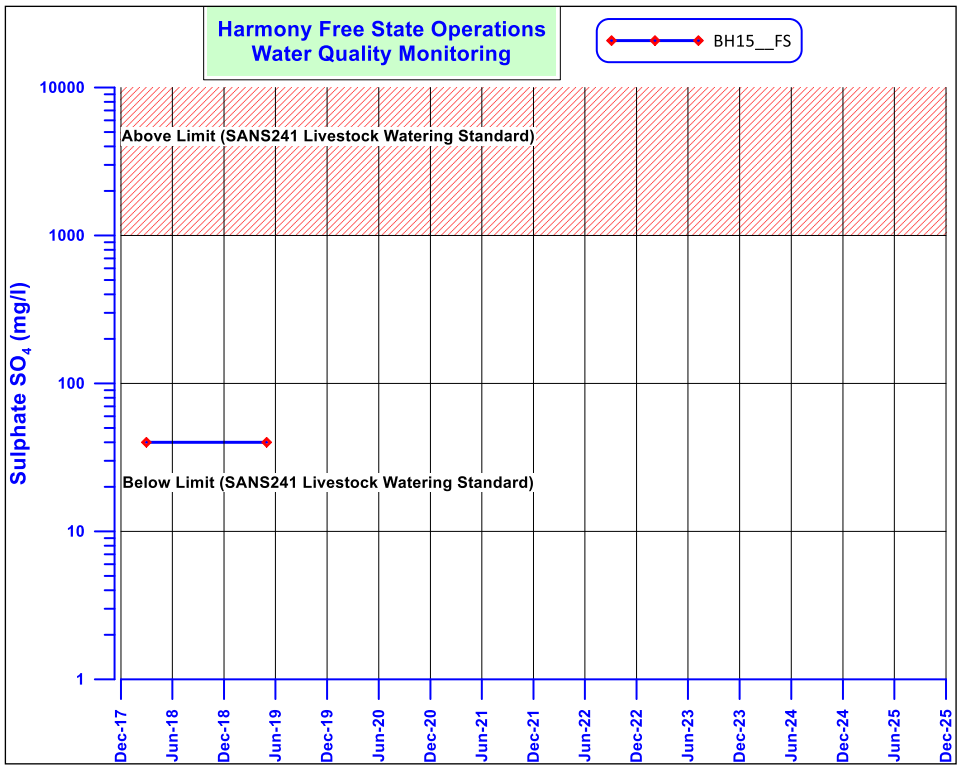

Harmony Free State Operations
Water Quality Monitoring
BH16__FS
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

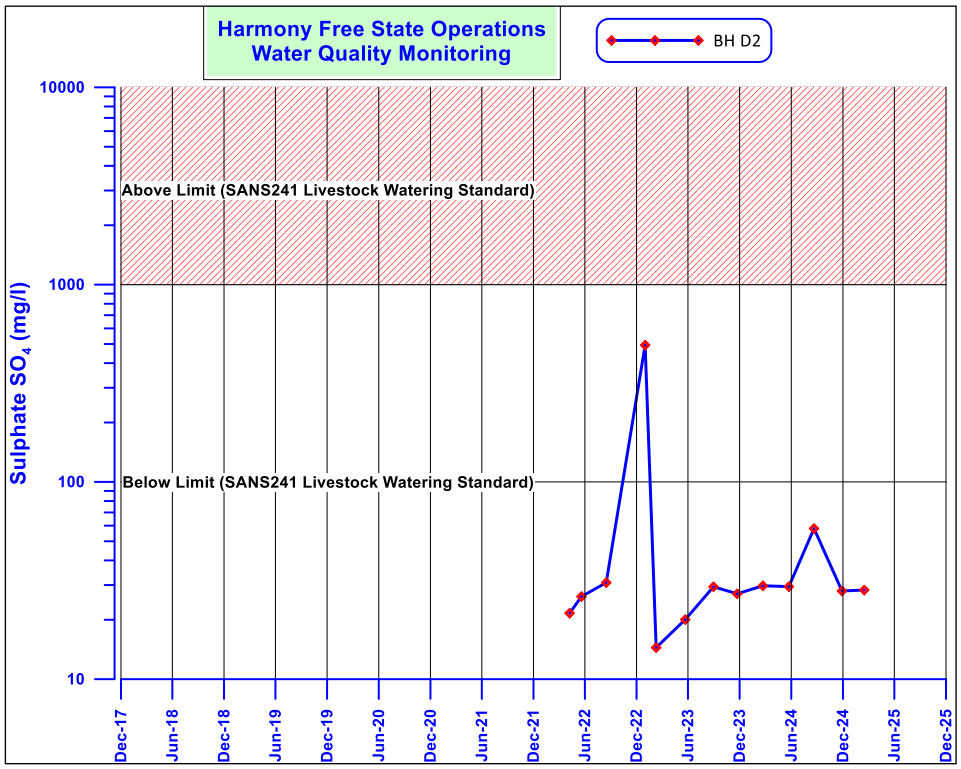

Harmony Free State Operations
Water Quality Monitoring
BH164
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

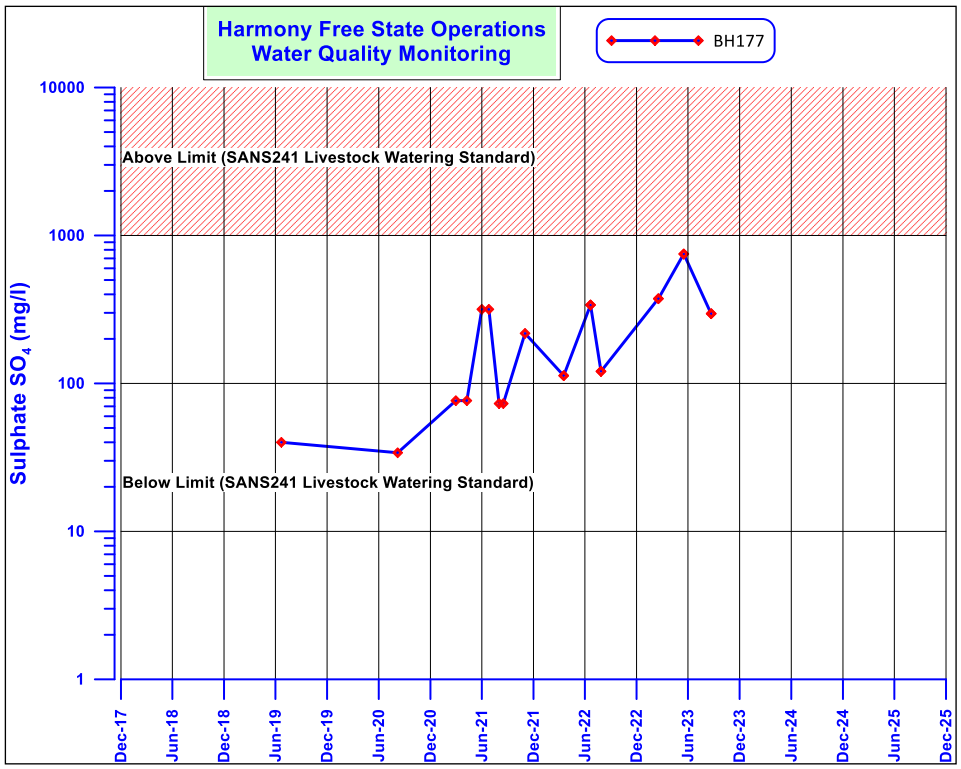

Harmony Free State Operations
Water Quality Monitoring
BH170
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

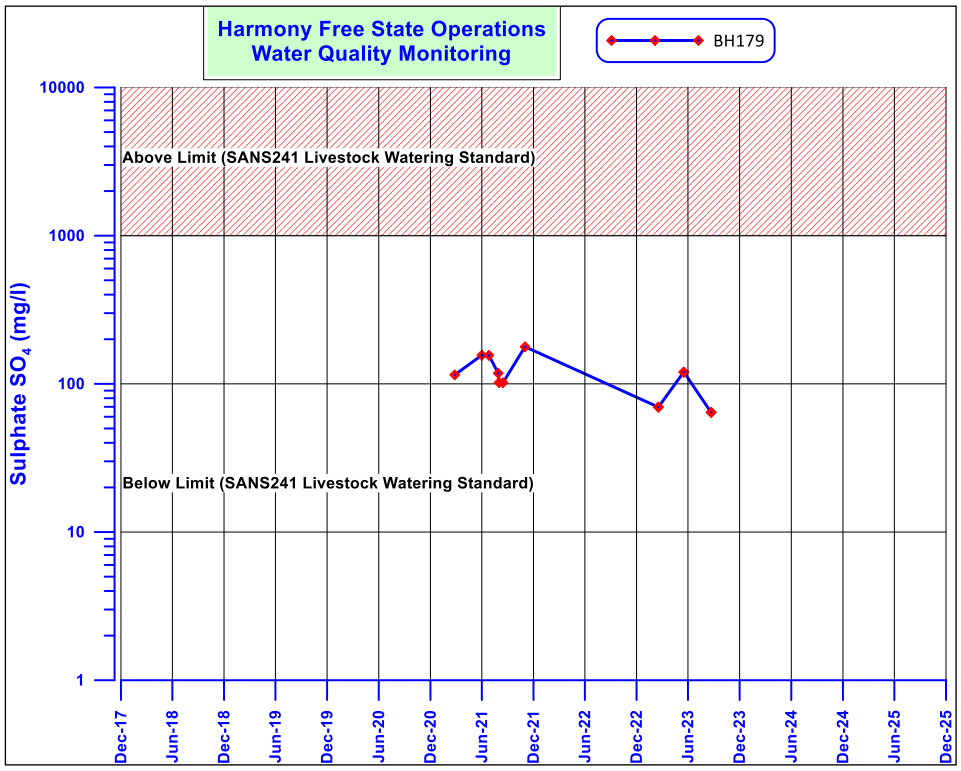

Harmony Free State Operations
Water Quality Monitoring
BH174
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

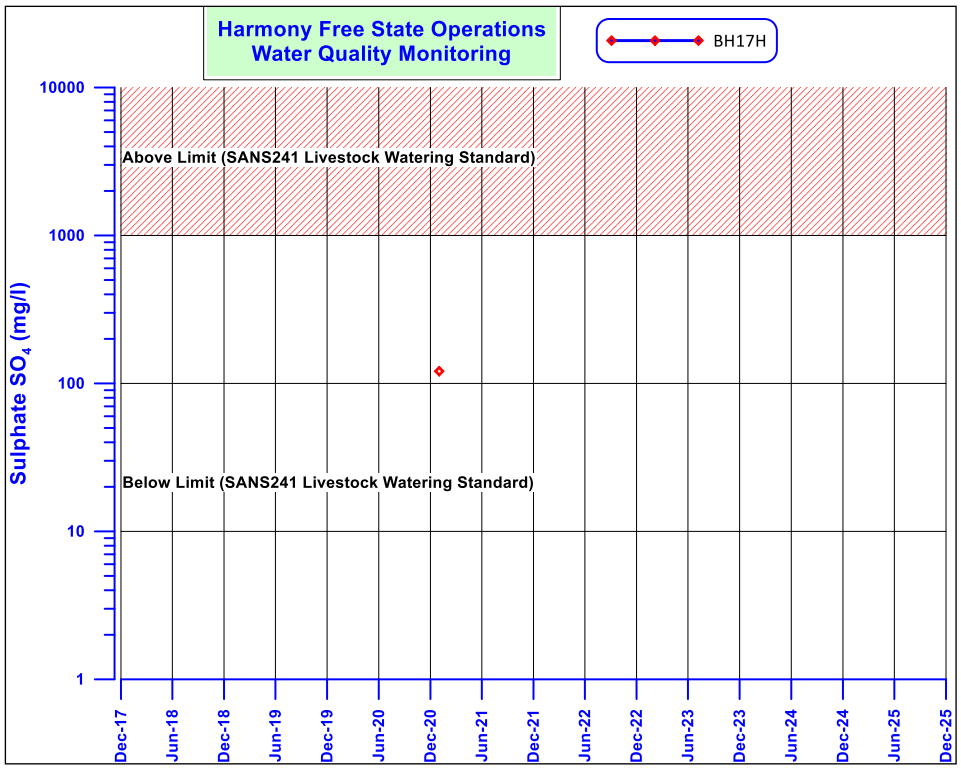

Harmony Free State Operations
Water Quality Monitoring
BH176
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

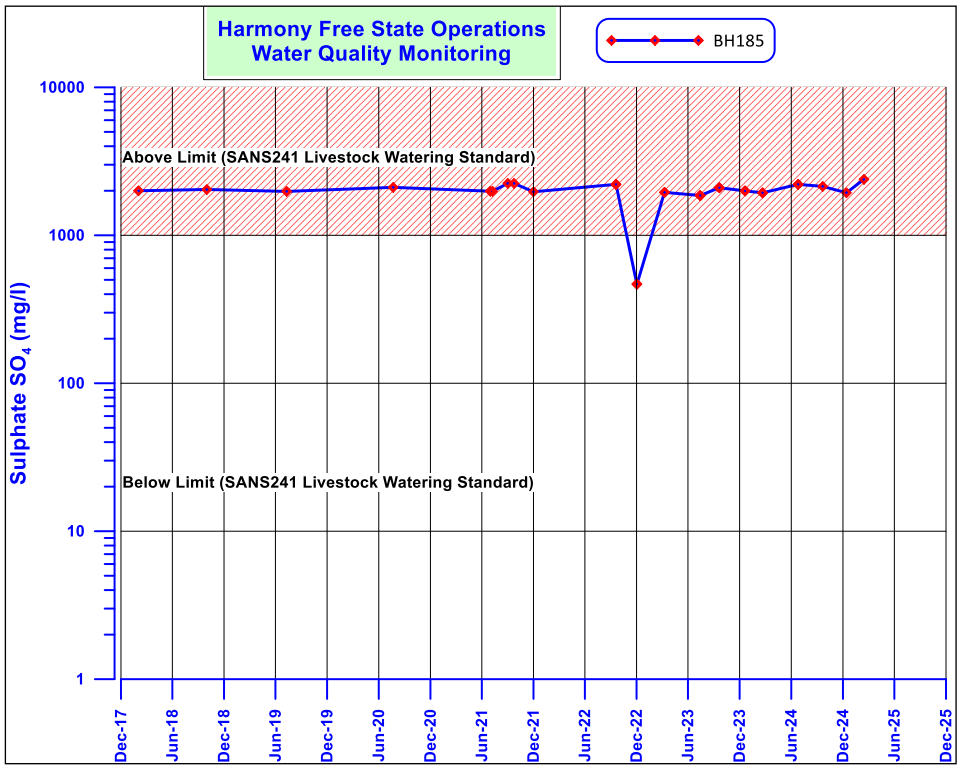

Harmony Free State Operations
Water Quality Monitoring
BH15__FS
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

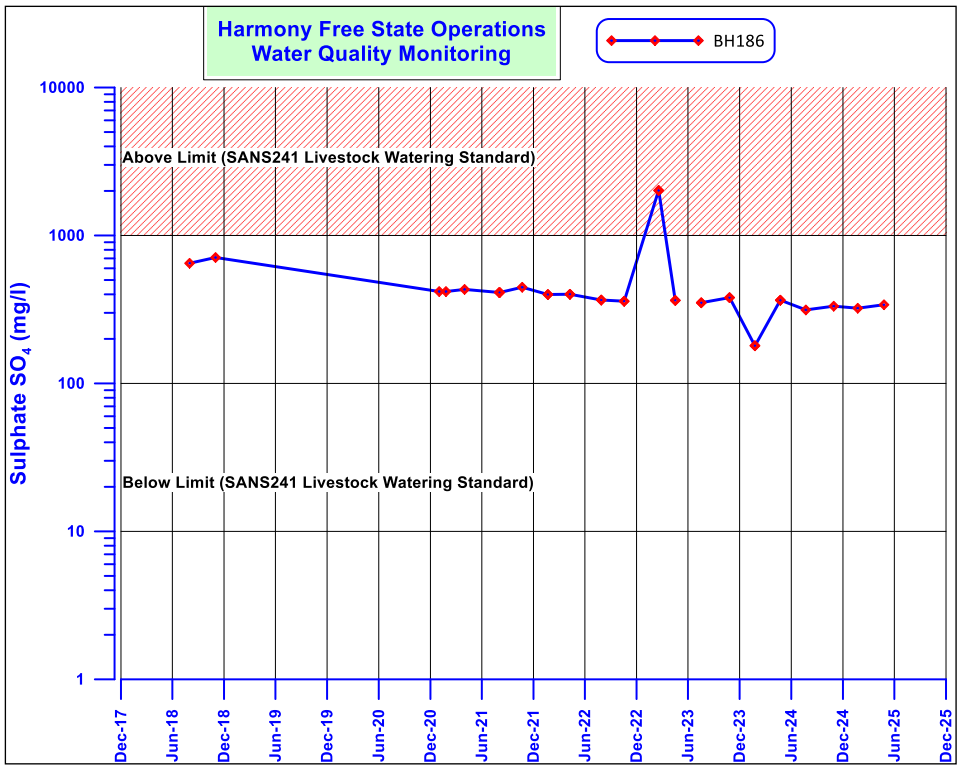

Harmony Free State Operations
Water Quality Monitoring
BH D2
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

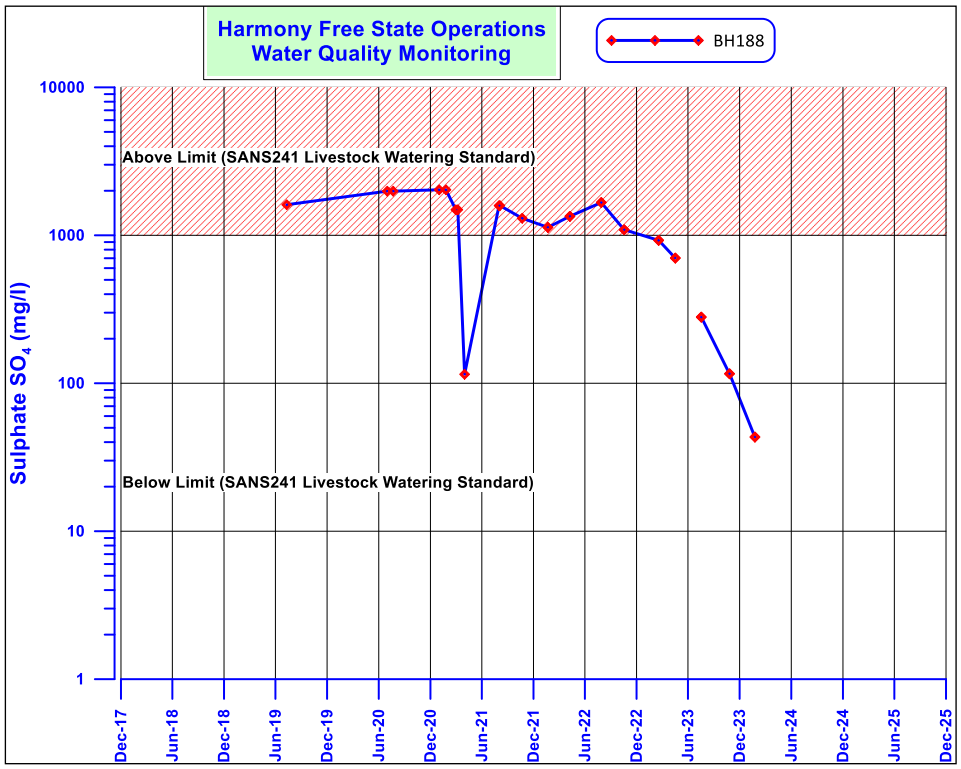

Harmony Free State Operations
Water Quality Monitoring
BH177
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

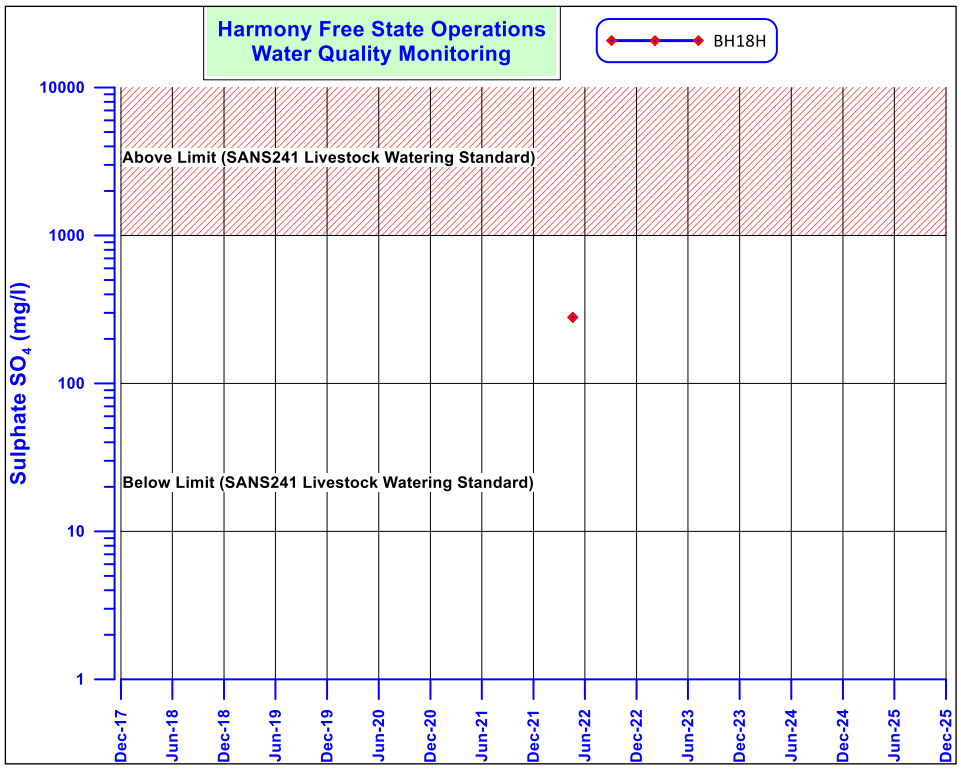

Harmony Free State Operations
Water Quality Monitoring
BH179
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

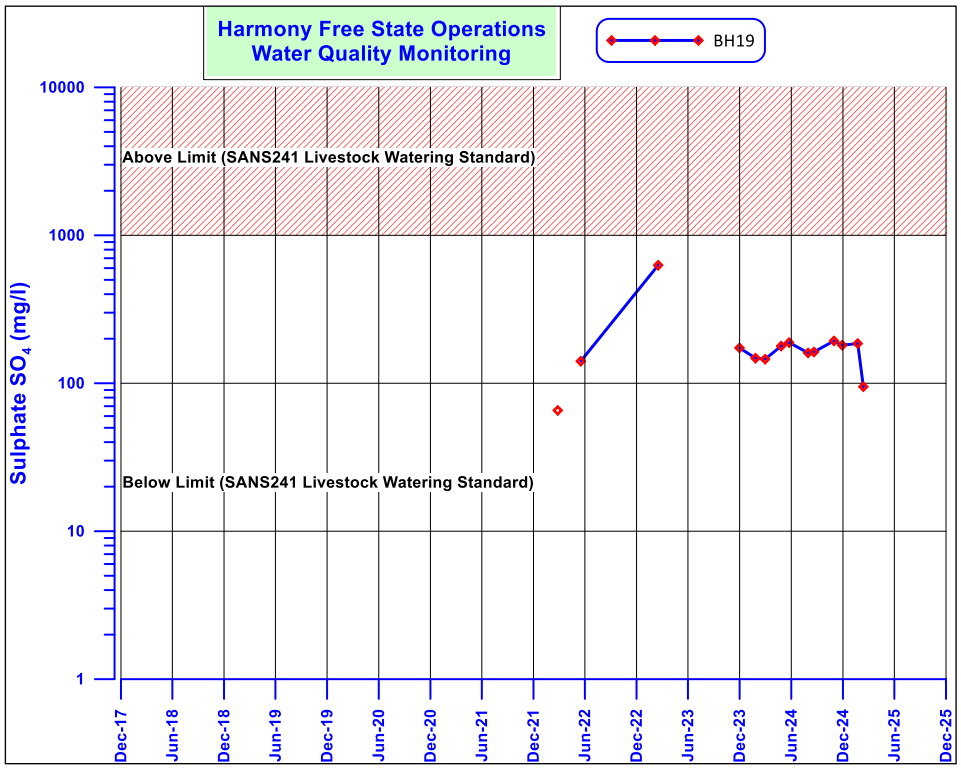

Harmony Free State Operations
Water Quality Monitoring
BH17H
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

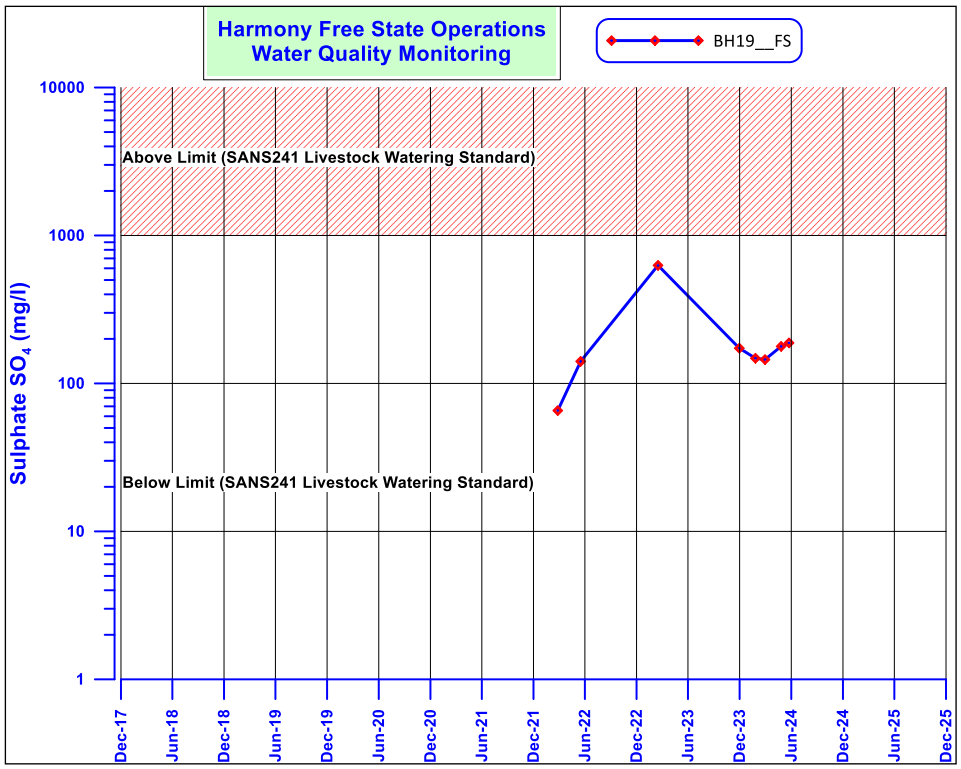

Harmony Free State Operations
Water Quality Monitoring
BH185
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

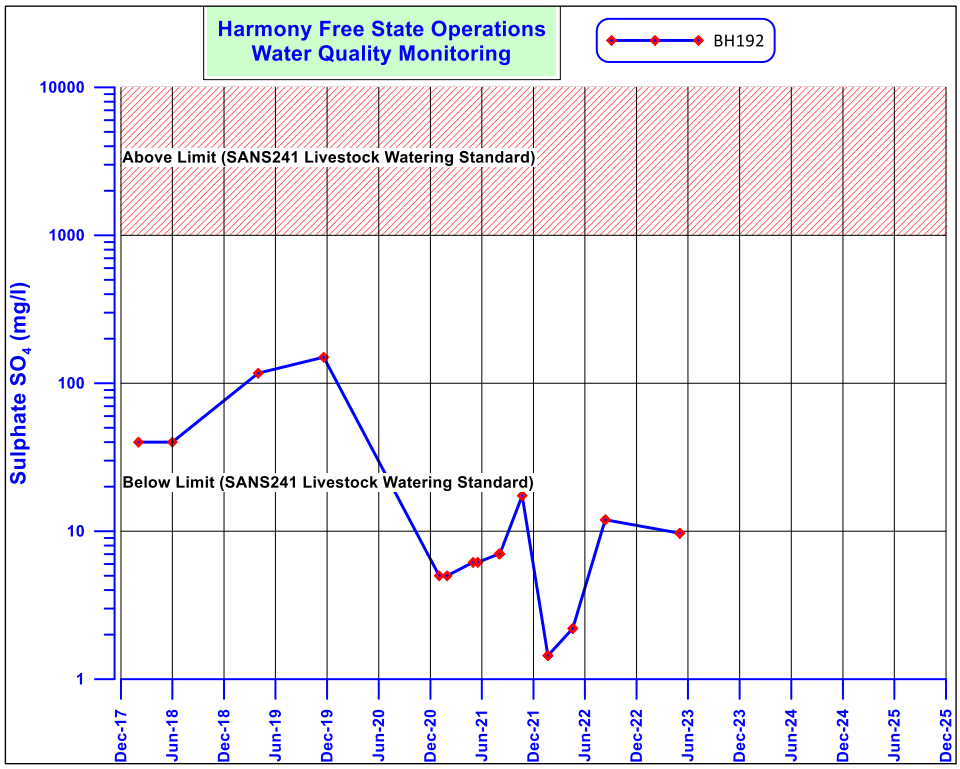

Harmony Free State Operations
Water Quality Monitoring
BH186
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

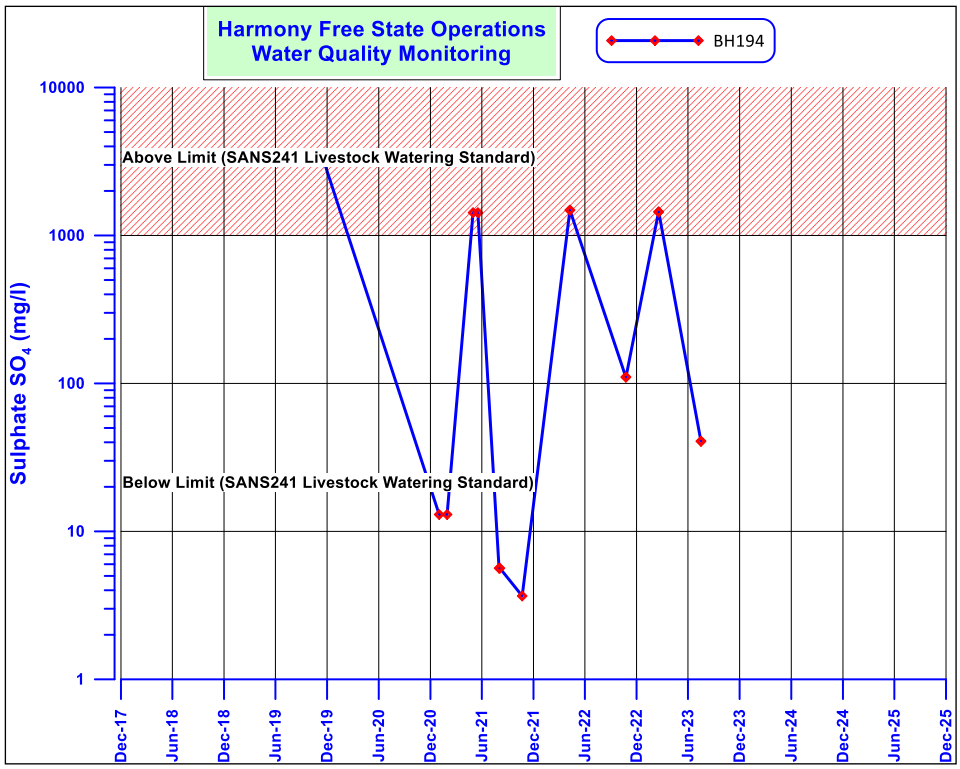

Harmony Free State Operations
Water Quality Monitoring
BH188
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

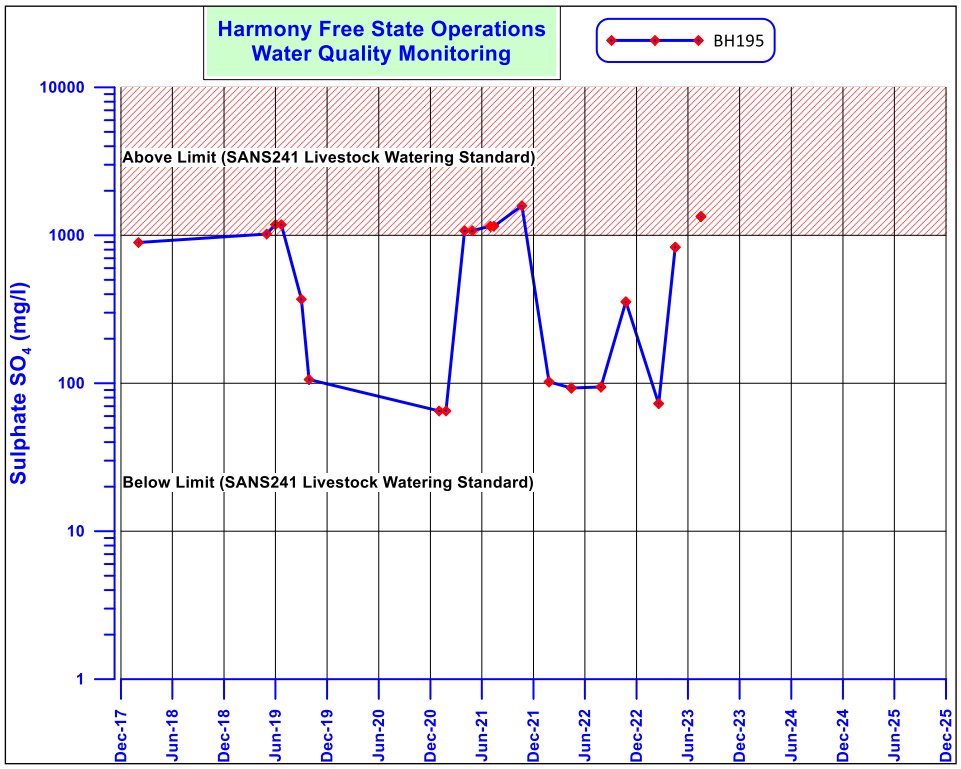

Harmony Free State Operations
Water Quality Monitoring
BH18H
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

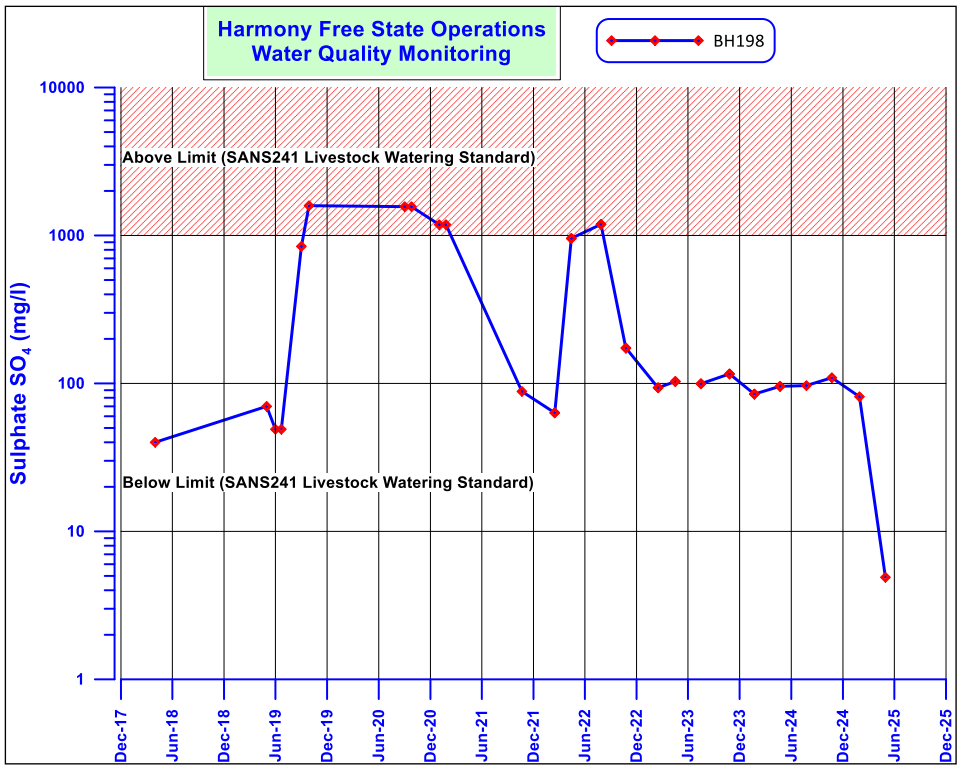

Harmony Free State Operations
Water Quality Monitoring
BH19
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

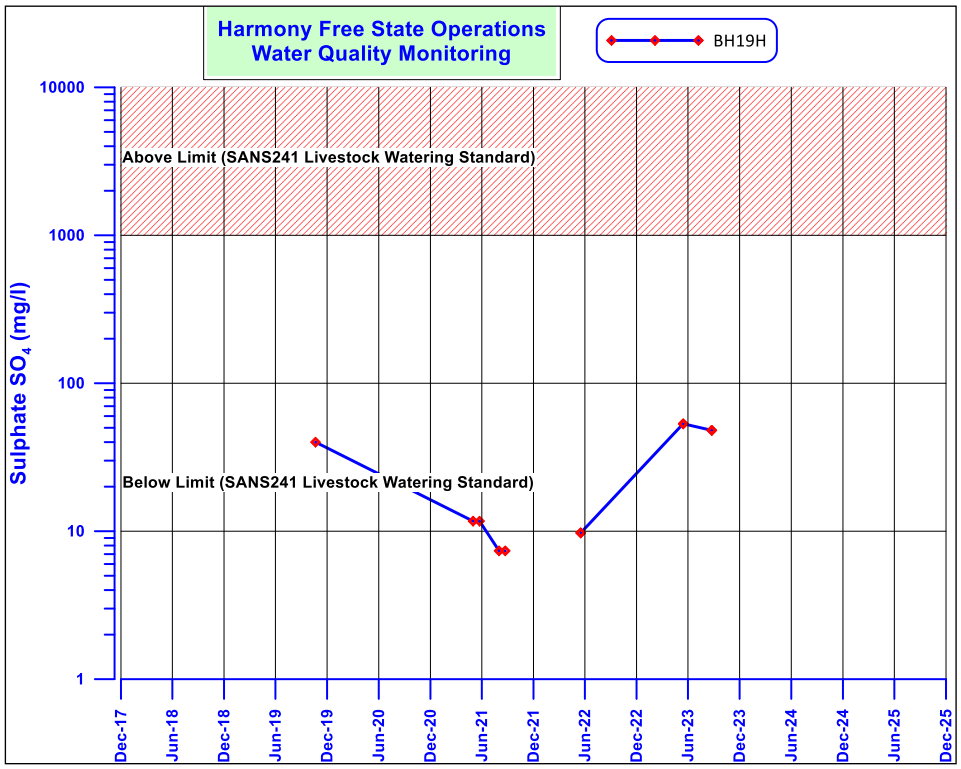

Harmony Free State Operations
Water Quality Monitoring
BH19__FS
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

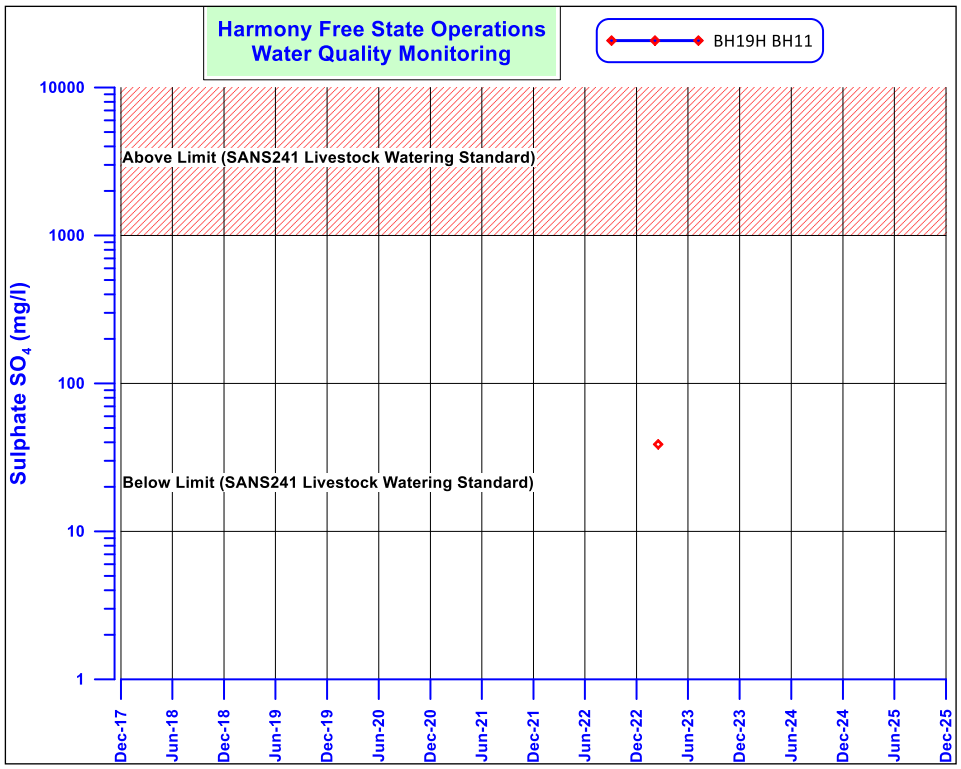

Harmony Free State Operations
Water Quality Monitoring
BH192
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

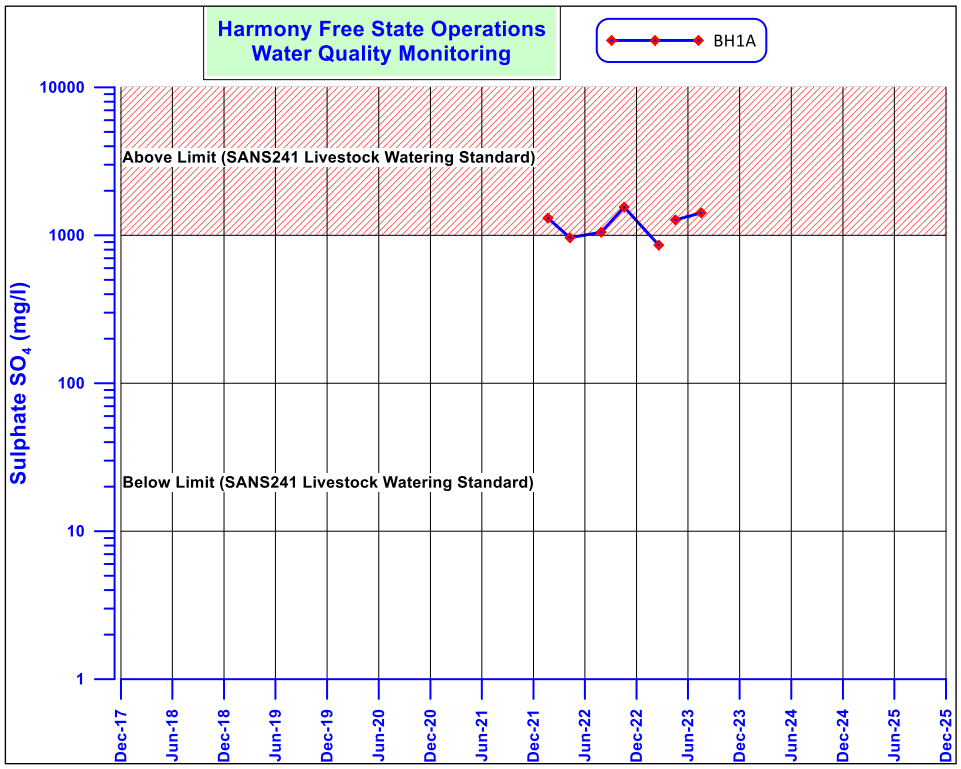

Harmony Free State Operations
Water Quality Monitoring
BH194
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

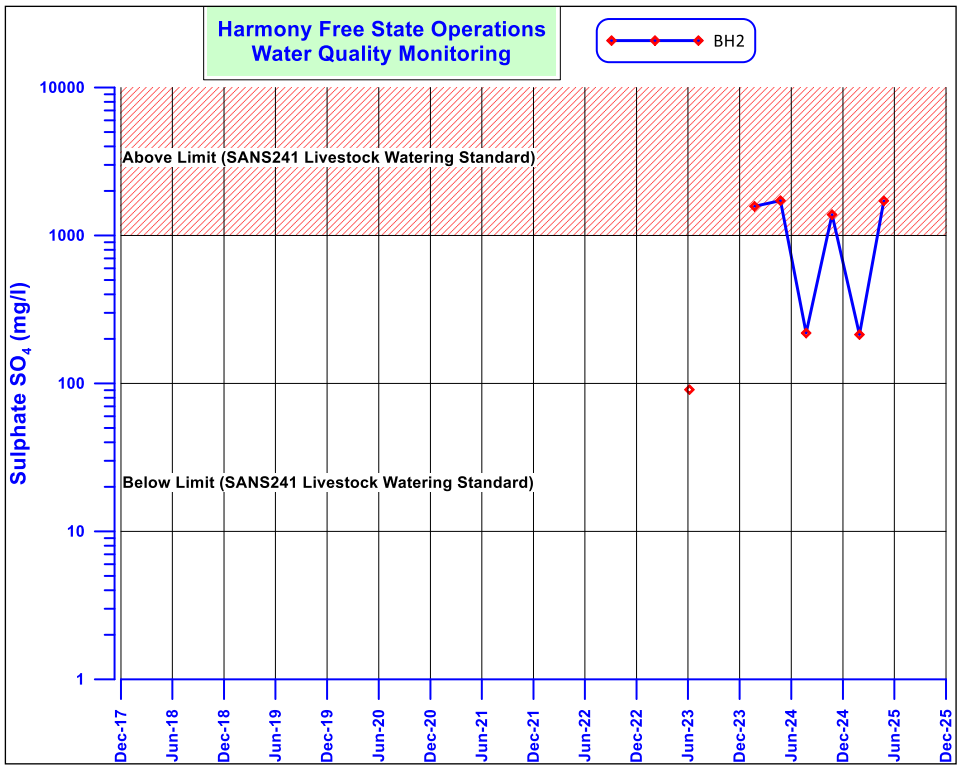

Harmony Free State Operations
Water Quality Monitoring
BH195
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

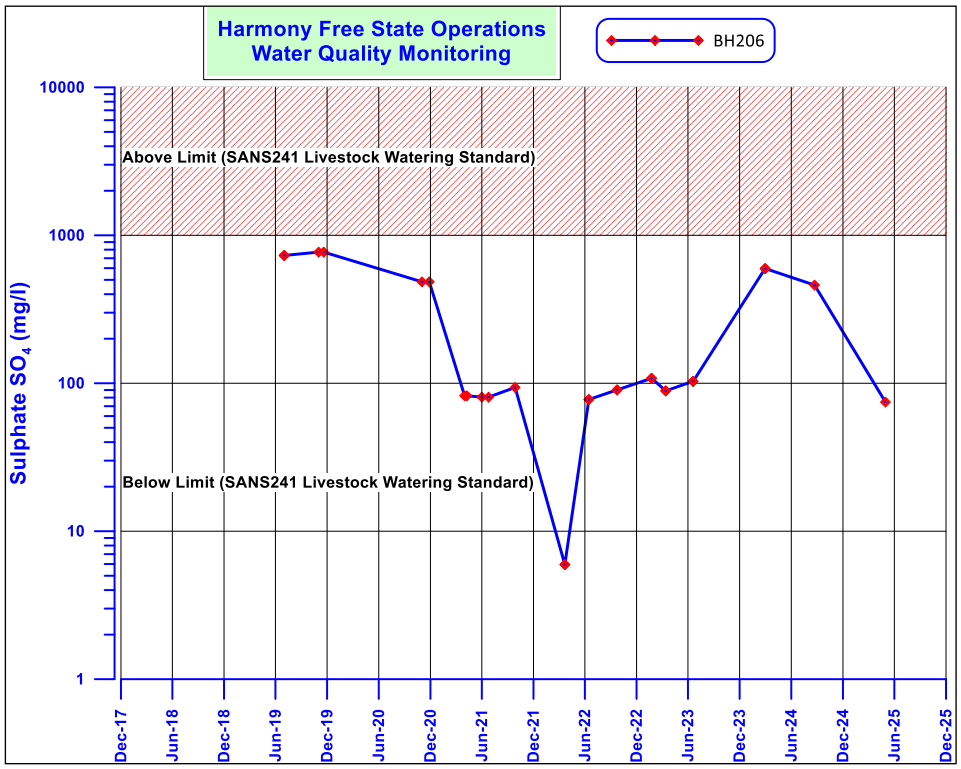

Harmony Free State Operations
Water Quality Monitoring
BH198
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

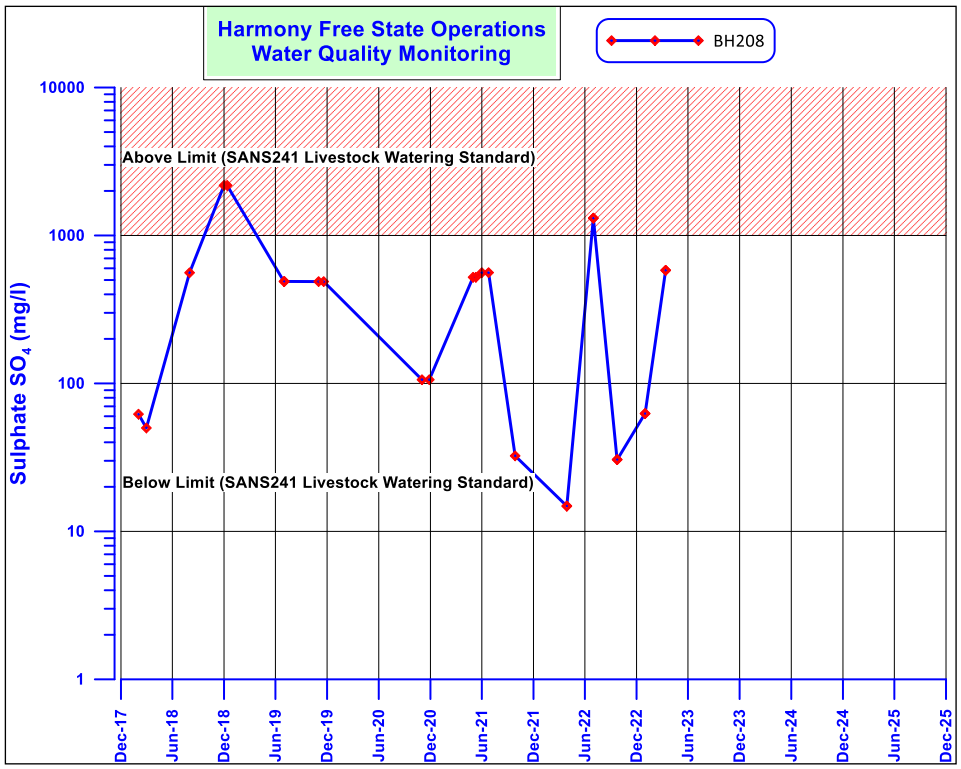

Harmony Free State Operations
Water Quality Monitoring
BH19H
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

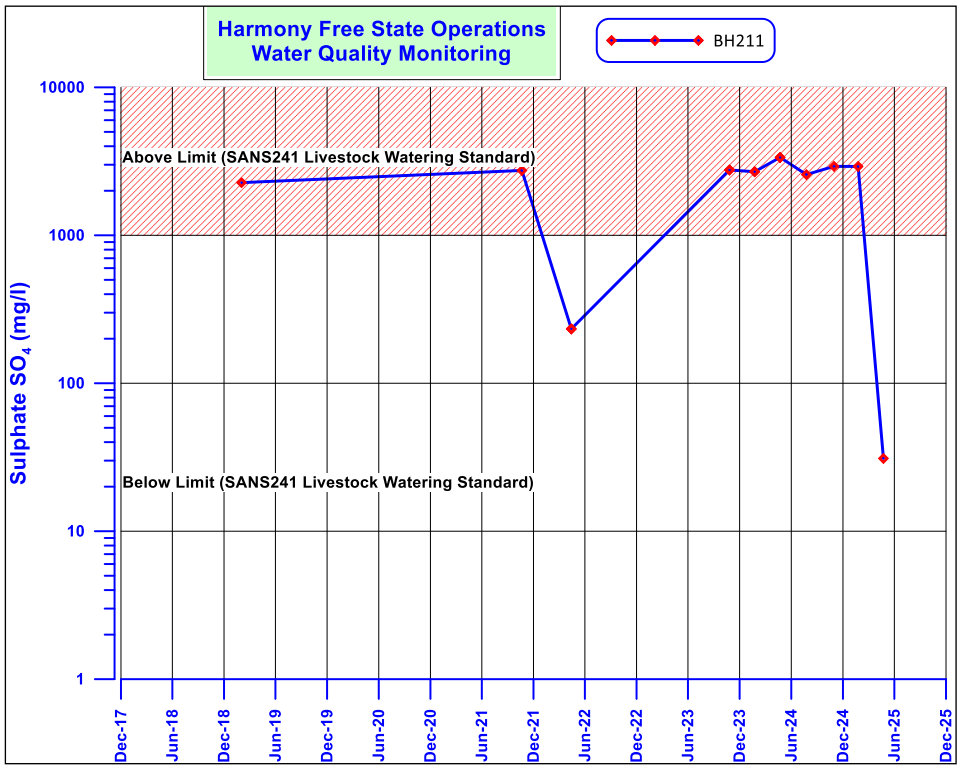

Harmony Free State Operations
Water Quality Monitoring
BH19H BH11
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

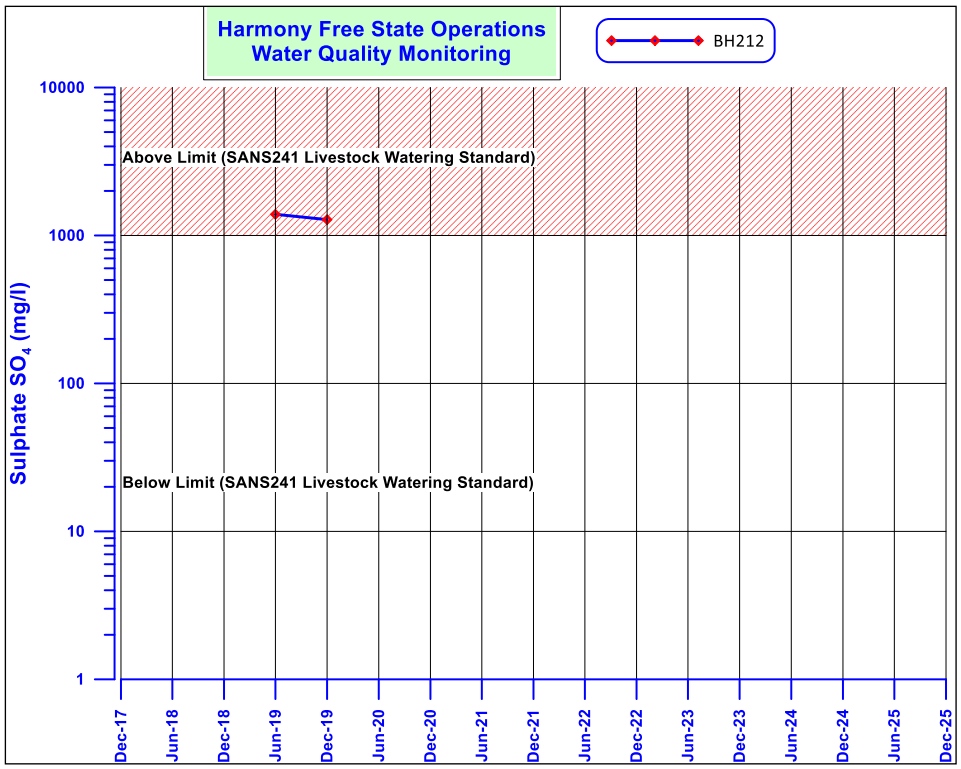

Harmony Free State Operations
Water Quality Monitoring
BH1A
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

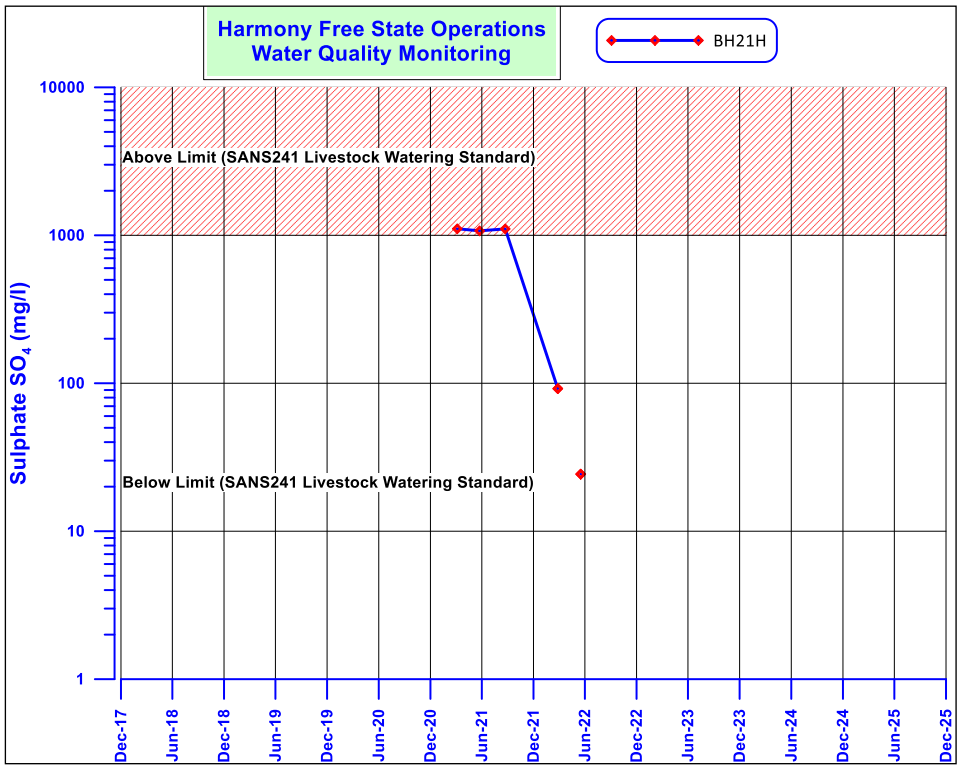

Harmony Free State Operations
Water Quality Monitoring
BH2
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

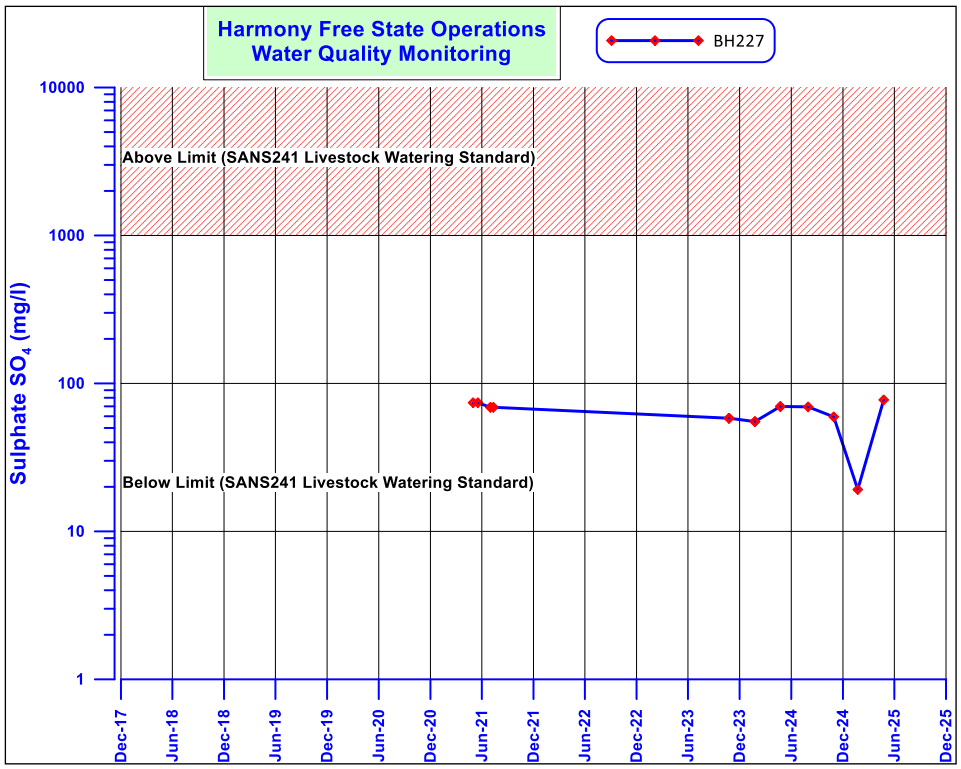

Harmony Free State Operations
Water Quality Monitoring
BH206
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

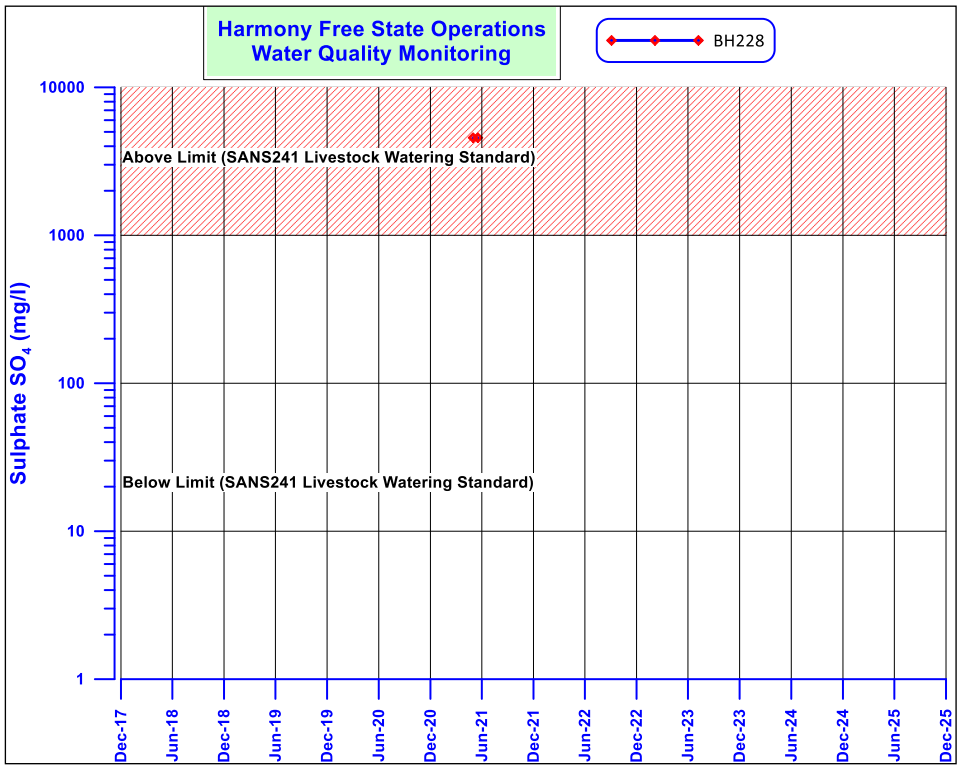

Harmony Free State Operations
Water Quality Monitoring
BH208
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

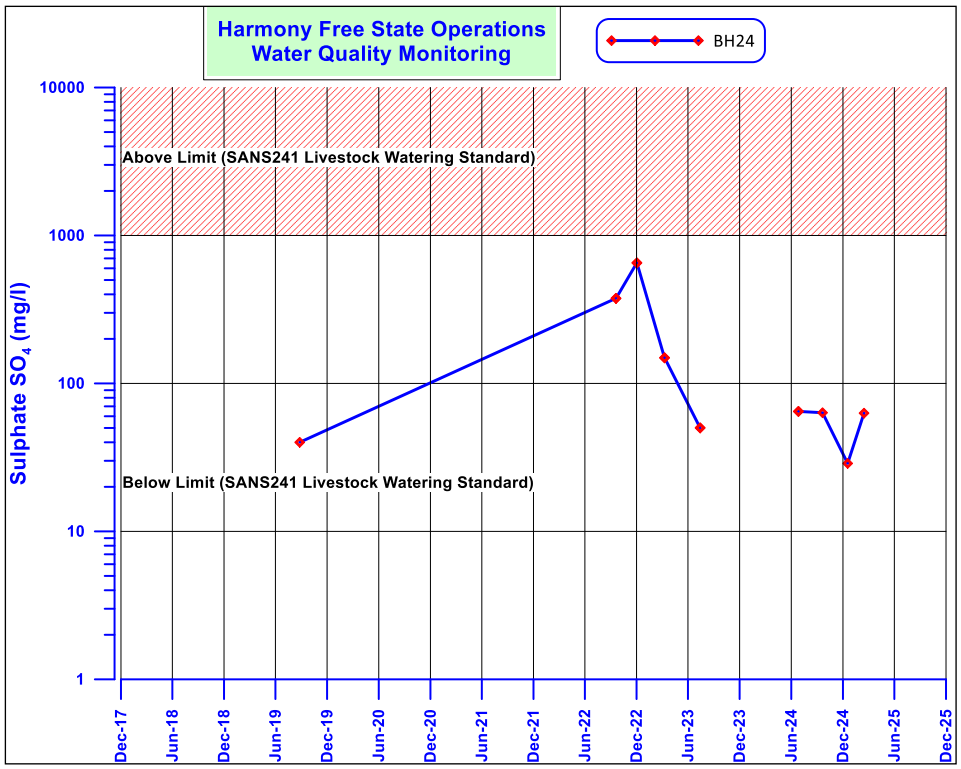

Harmony Free State Operations
Water Quality Monitoring
BH211
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

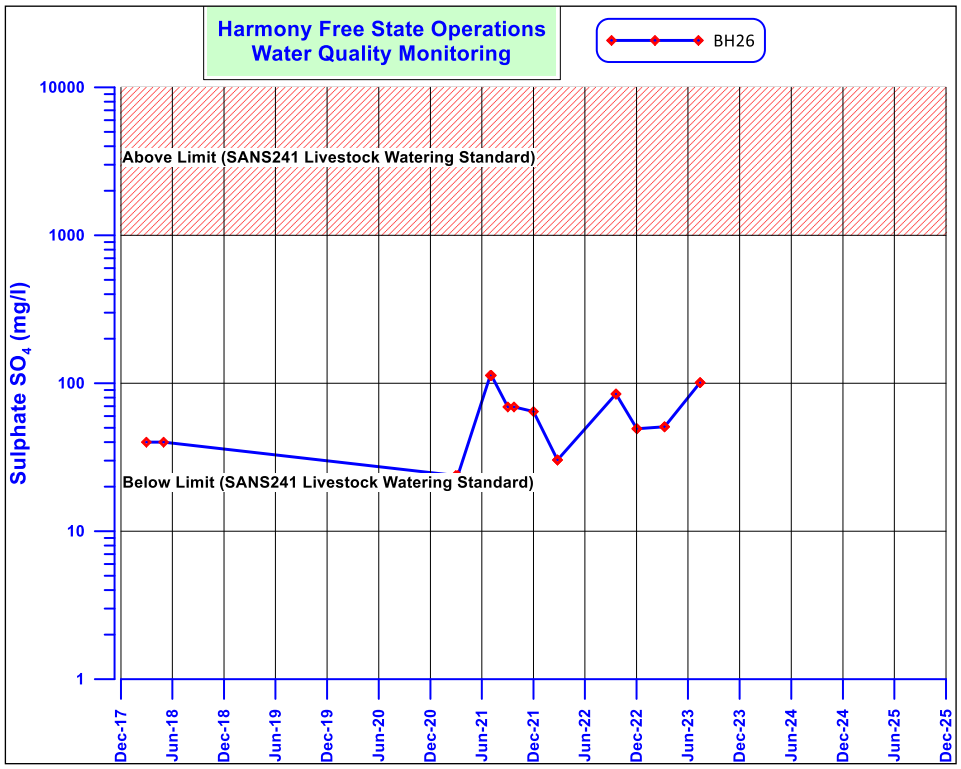

Harmony Free State Operations
Water Quality Monitoring
BH212
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

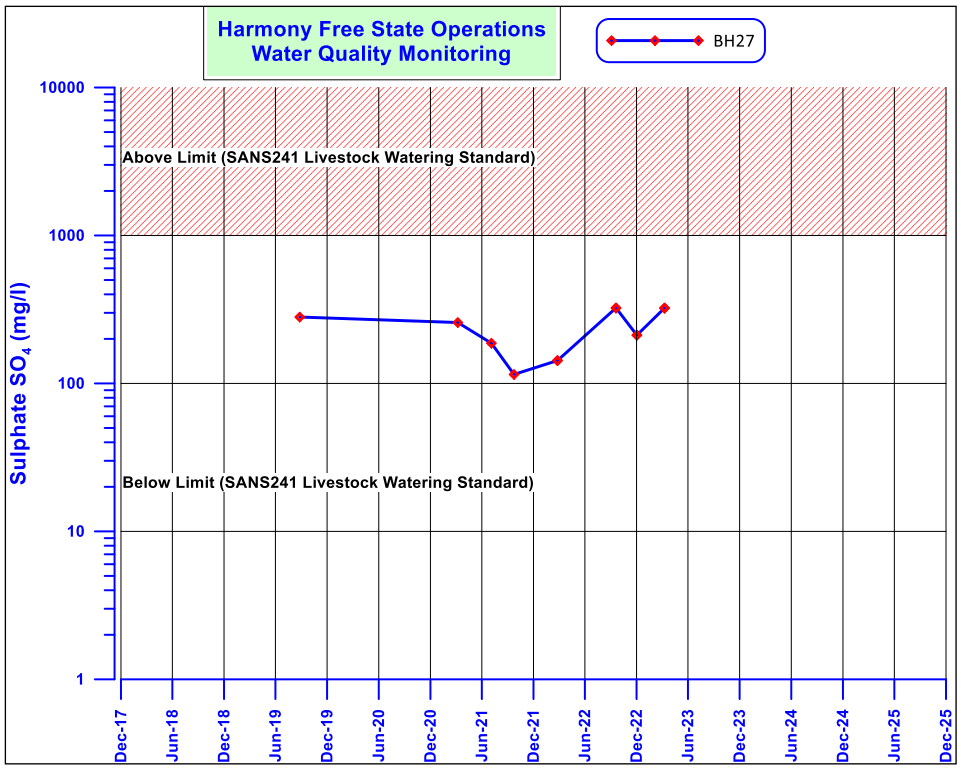

Harmony Free State Operations
Water Quality Monitoring
BH21H
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

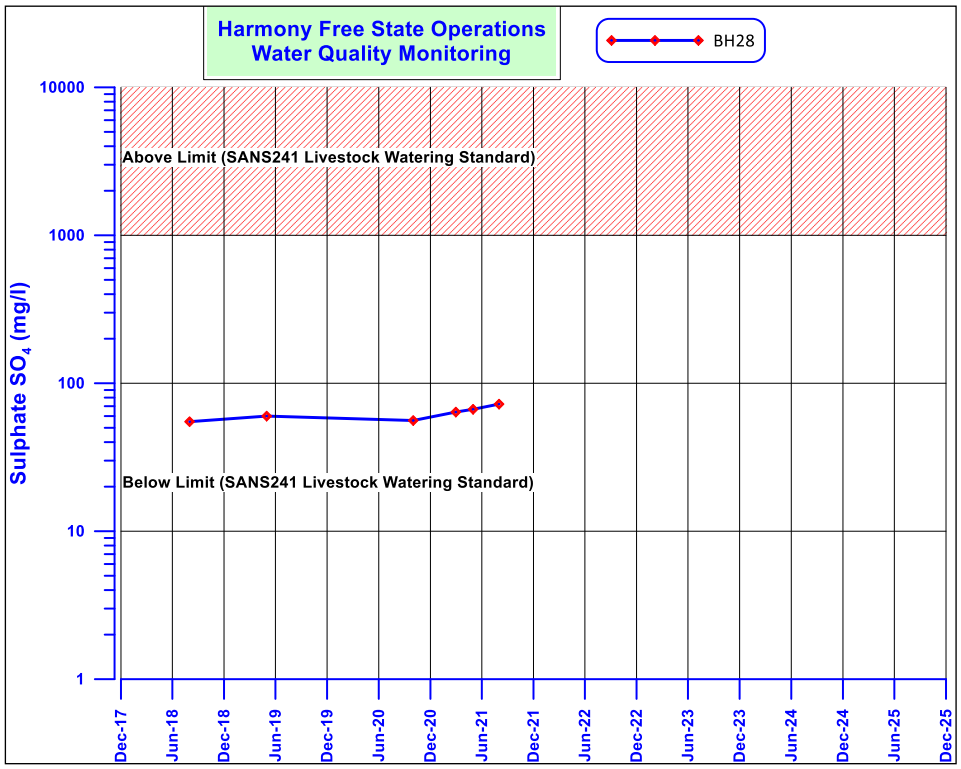

Harmony Free State Operations
Water Quality Monitoring
BH227
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

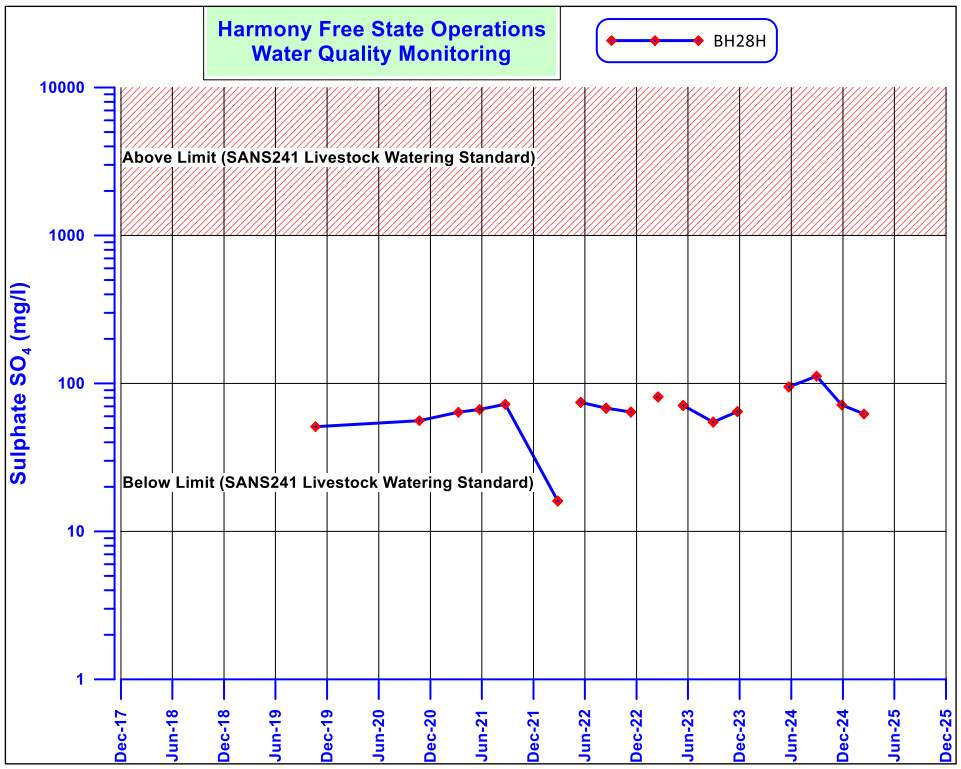

Harmony Free State Operations
Water Quality Monitoring
BH228
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

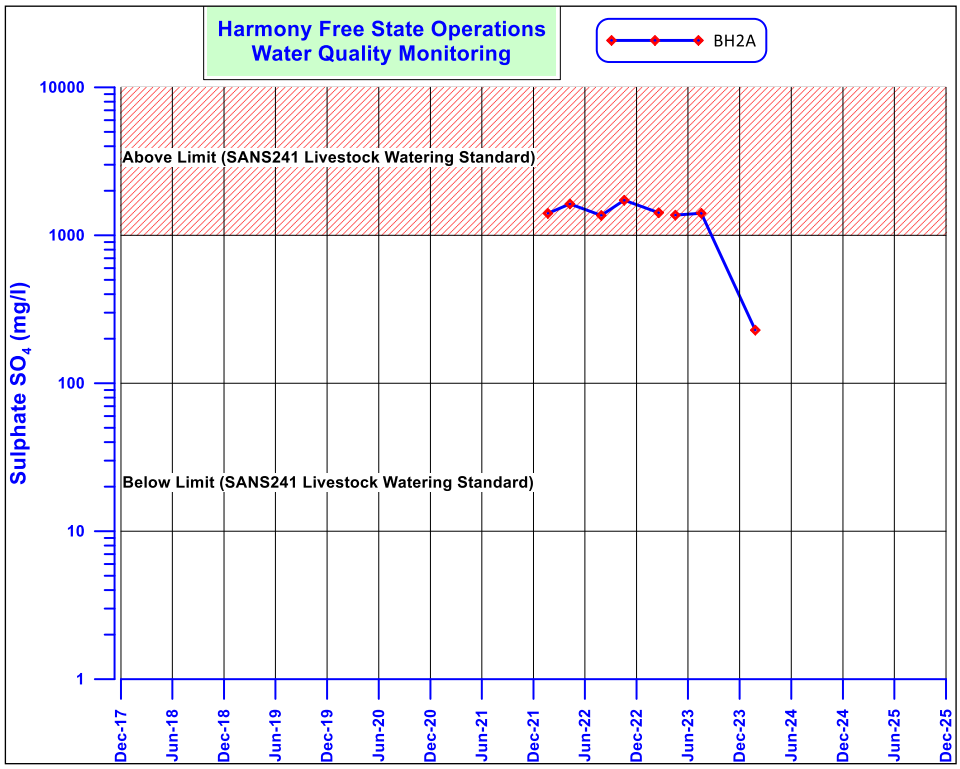

Harmony Free State Operations
Water Quality Monitoring
BH24
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

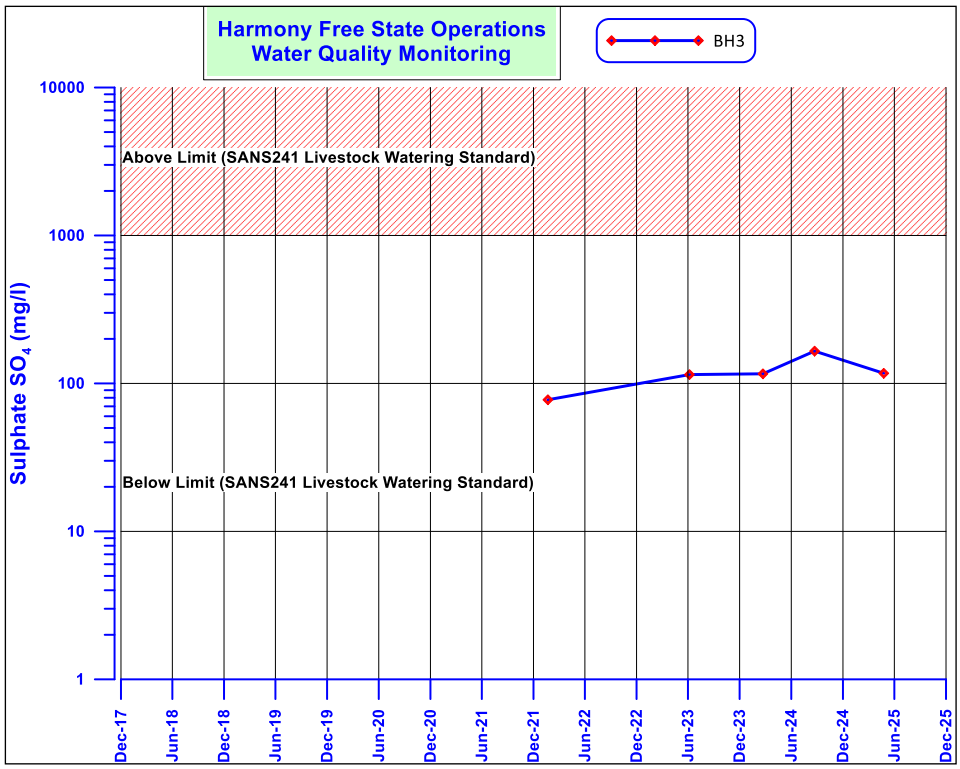

Harmony Free State Operations
Water Quality Monitoring
BH26
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

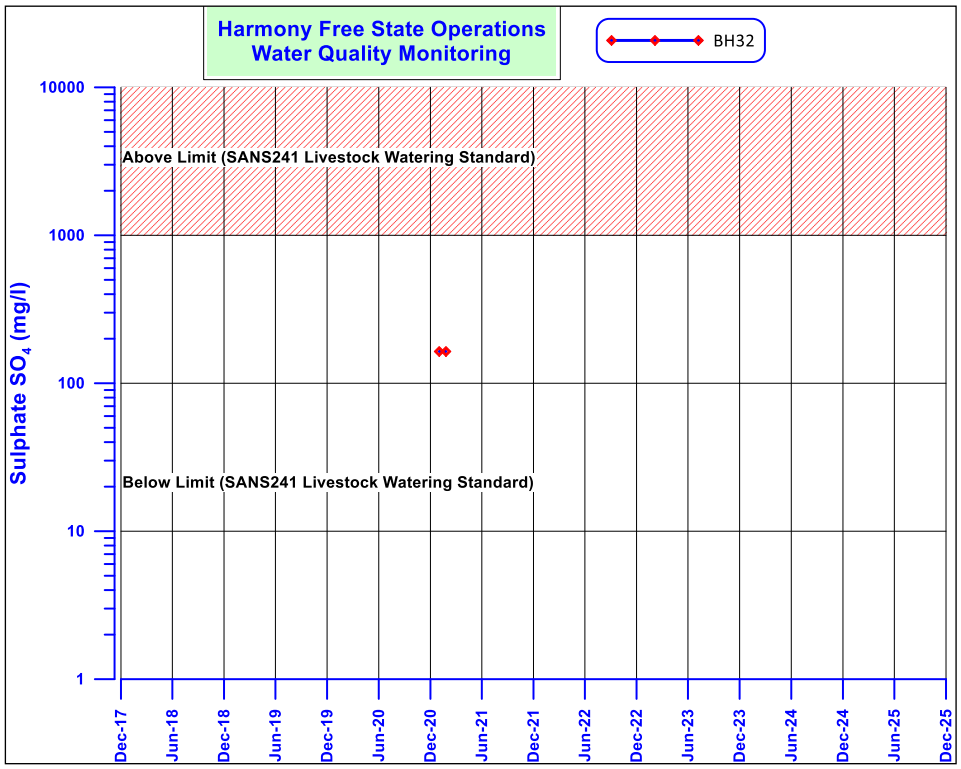

Harmony Free State Operations
Water Quality Monitoring
BH27
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

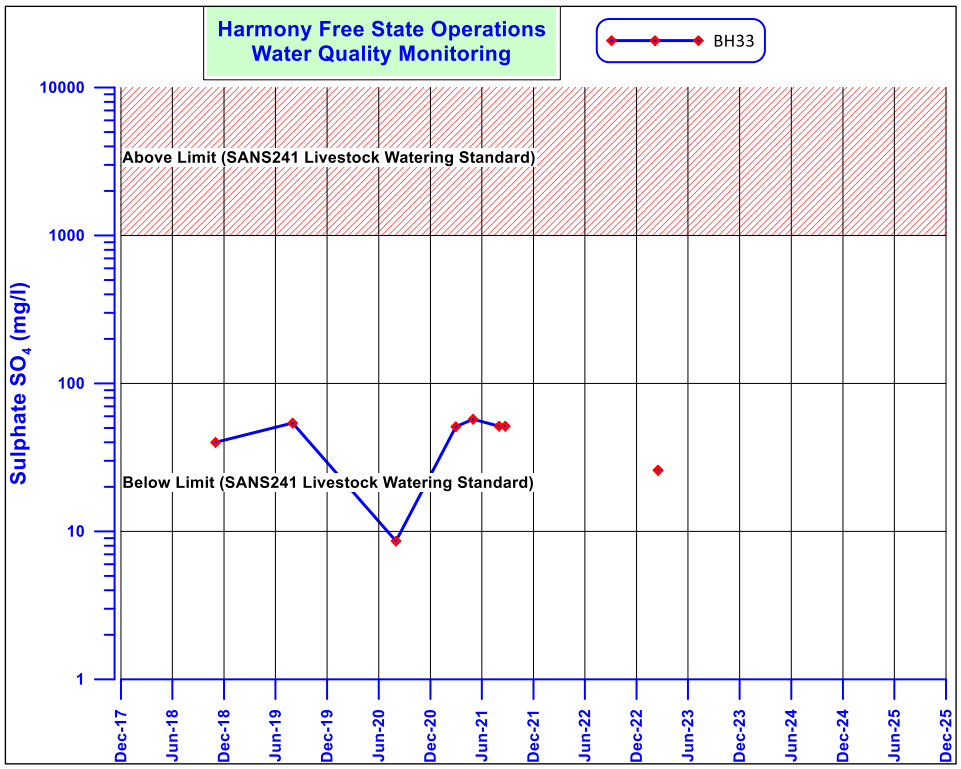

Harmony Free State Operations
Water Quality Monitoring
BH28
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

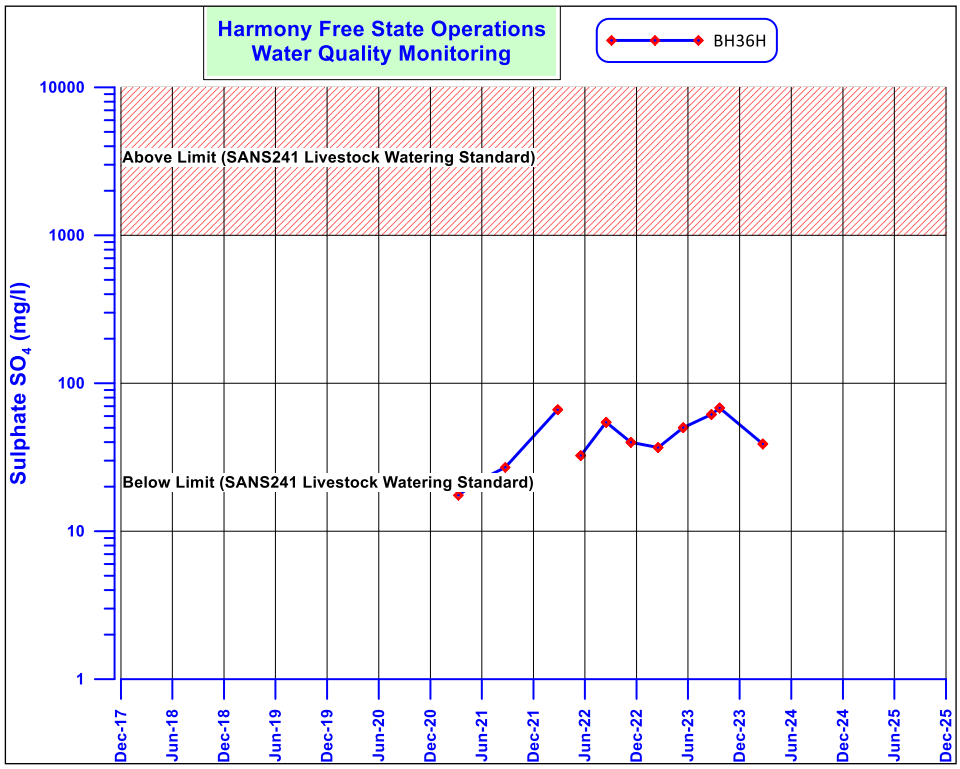

Harmony Free State Operations
Water Quality Monitoring
BH28H
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

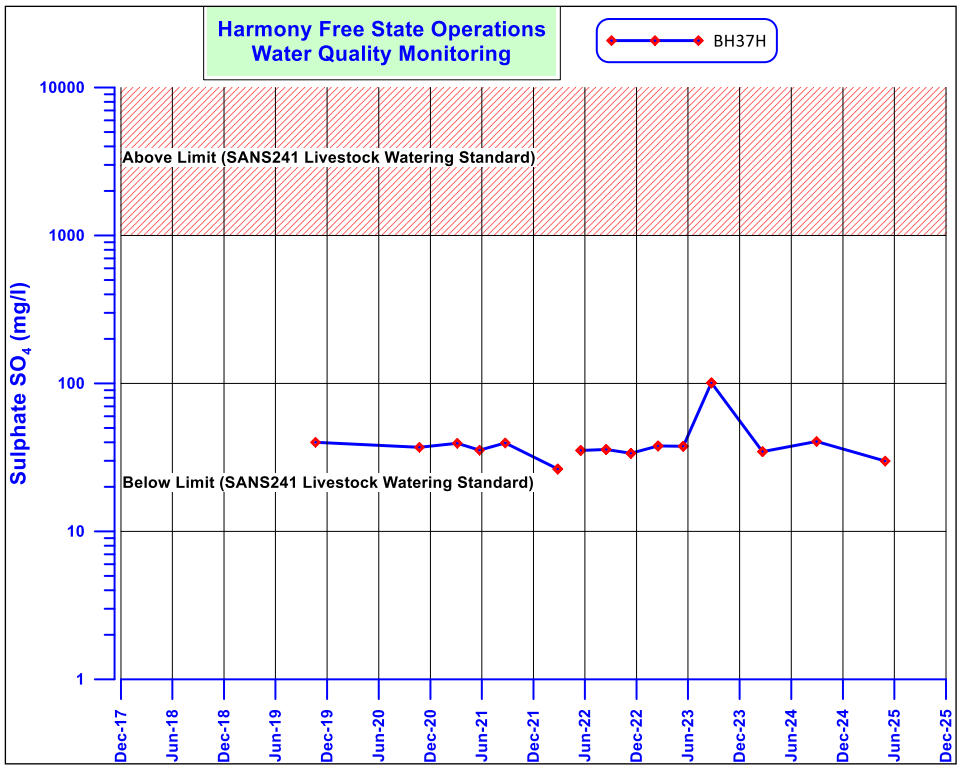

Harmony Free State Operations
Water Quality Monitoring
BH2A
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

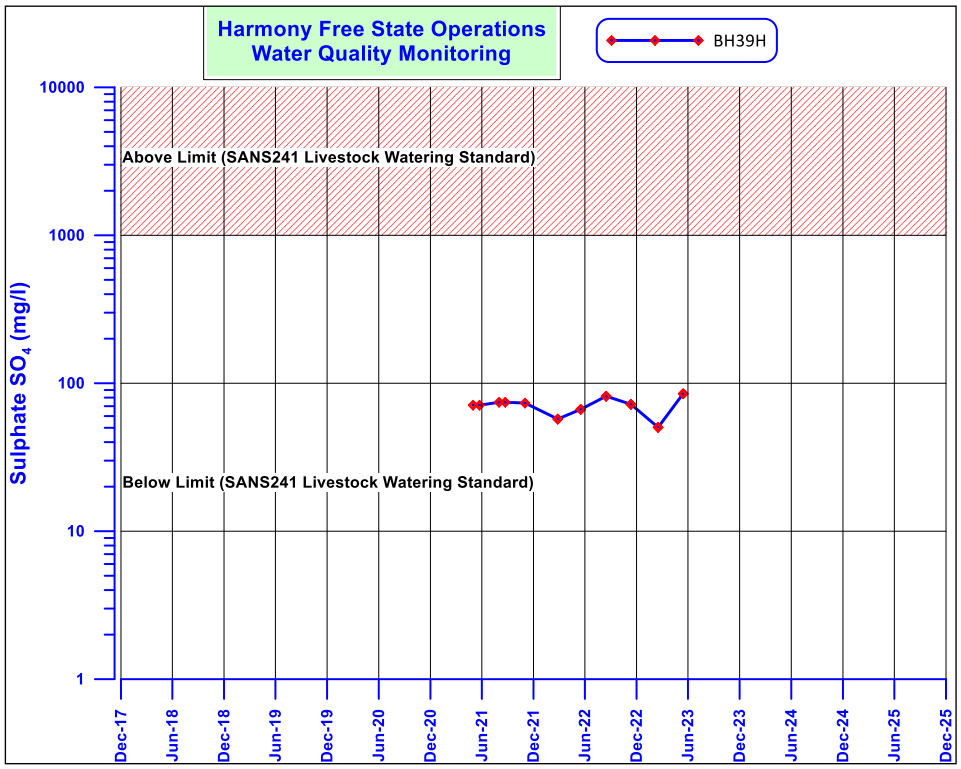

Harmony Free State Operations
Water Quality Monitoring
BH3
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

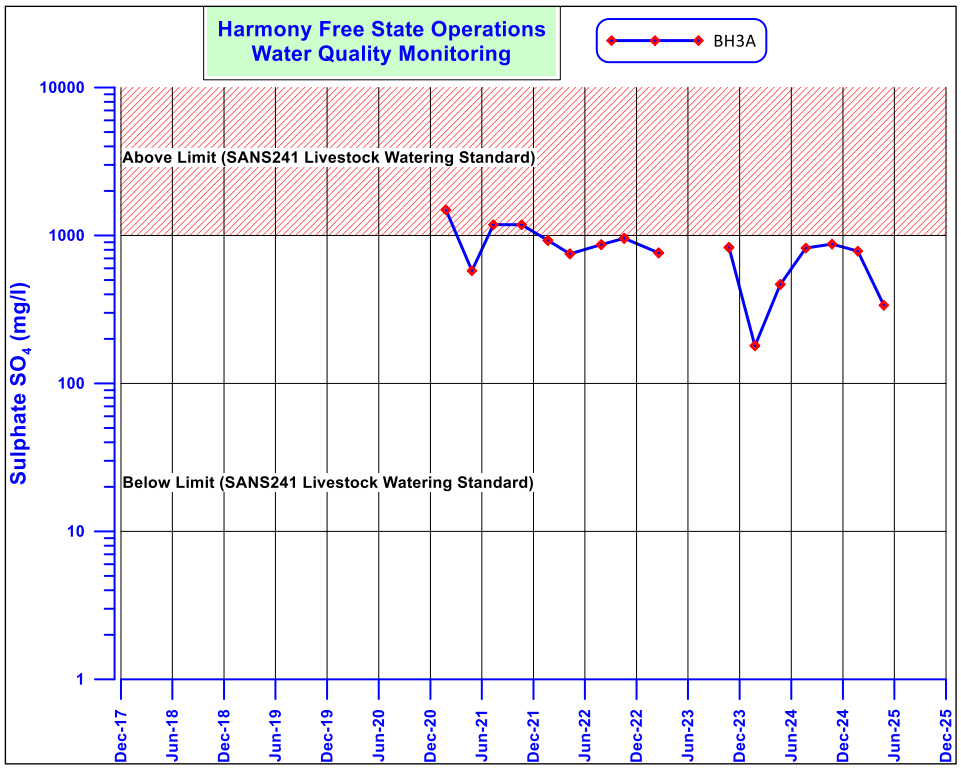

Harmony Free State Operations
Water Quality Monitoring
BH32
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

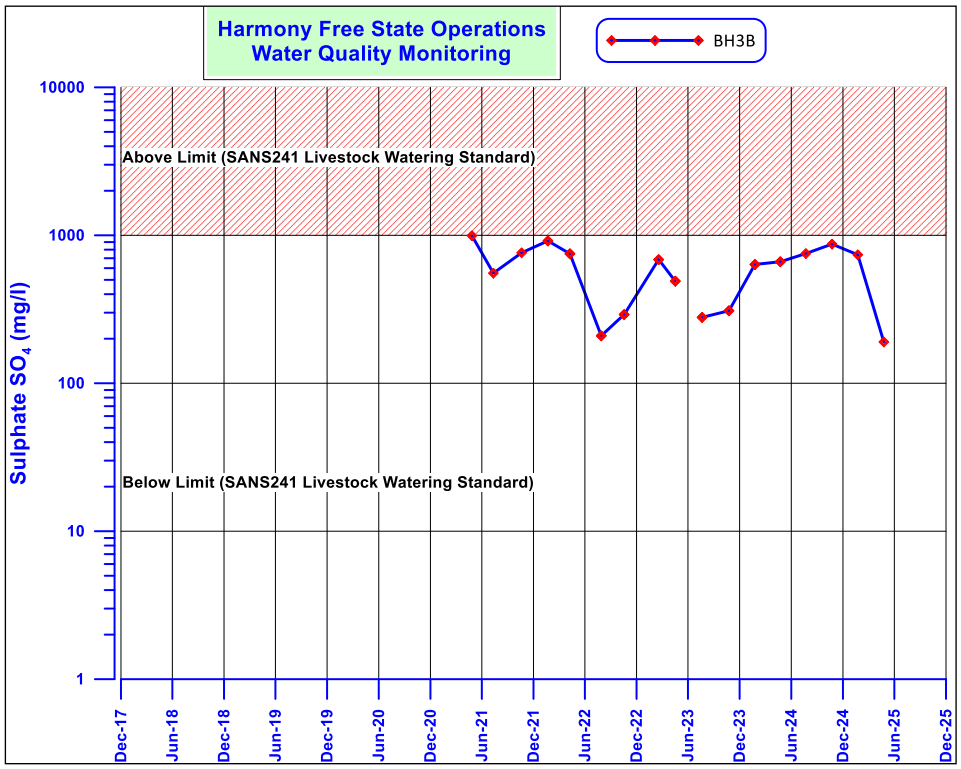

Harmony Free State Operations
Water Quality Monitoring
BH33
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

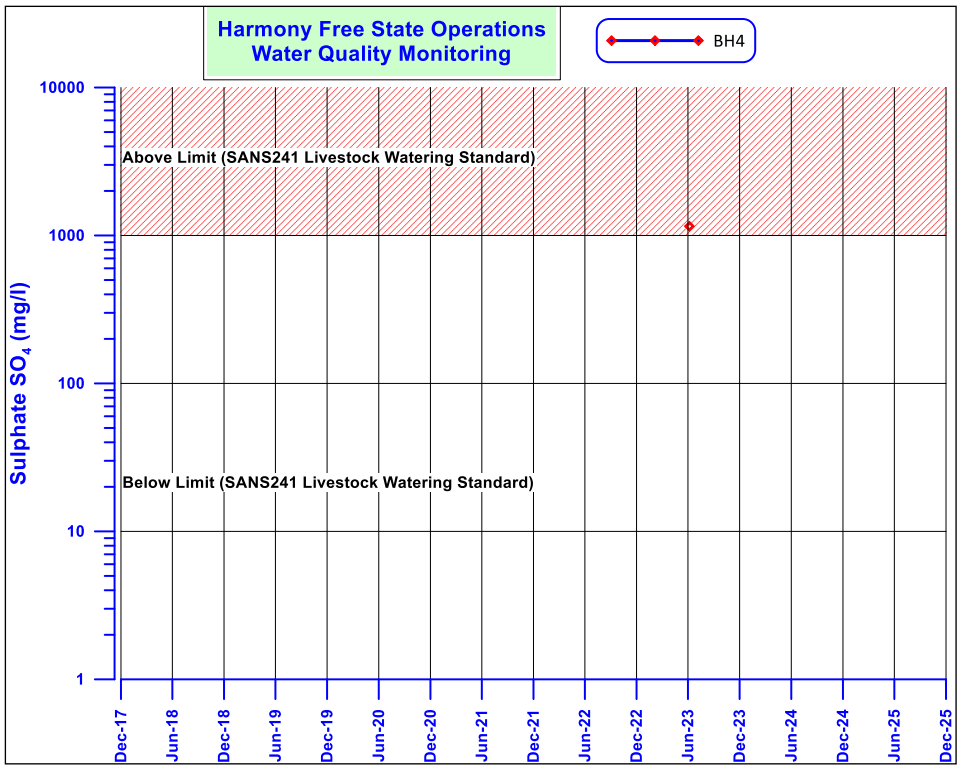

Harmony Free State Operations
Water Quality Monitoring
BH36H
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

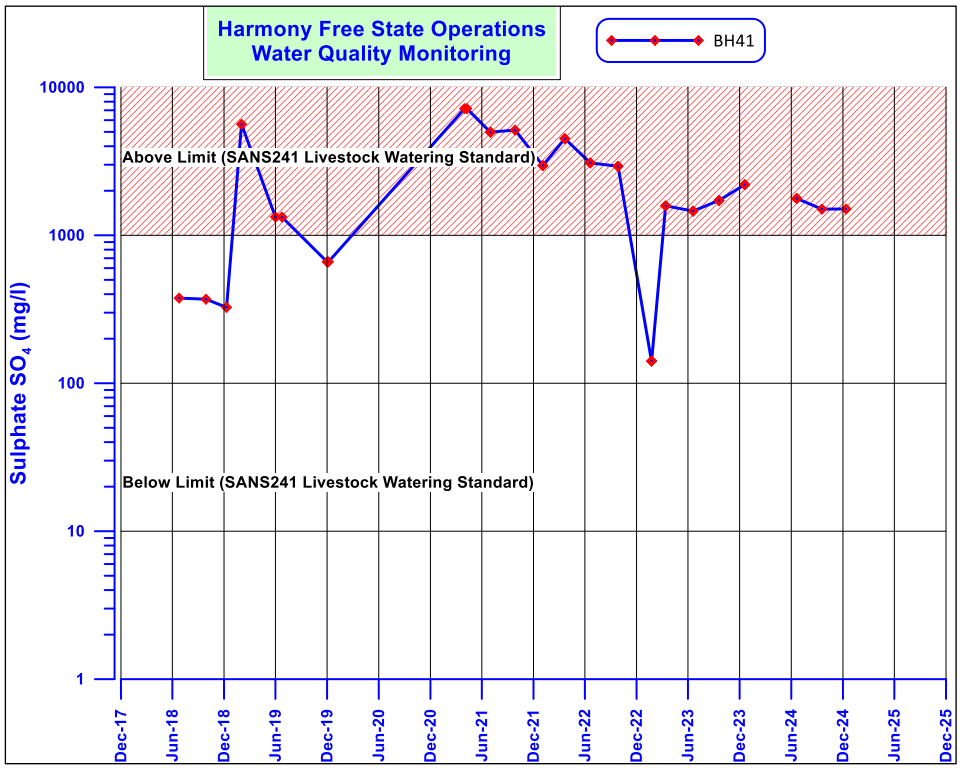

Harmony Free State Operations
Water Quality Monitoring
BH37H
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

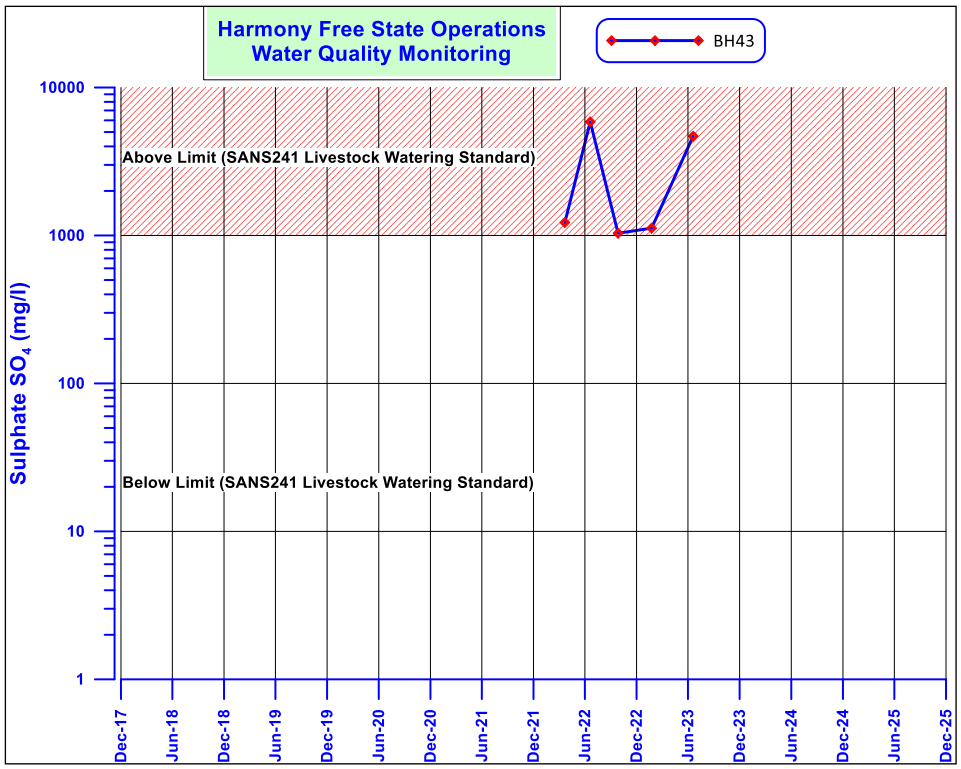

Harmony Free State Operations
Water Quality Monitoring
BH39H
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

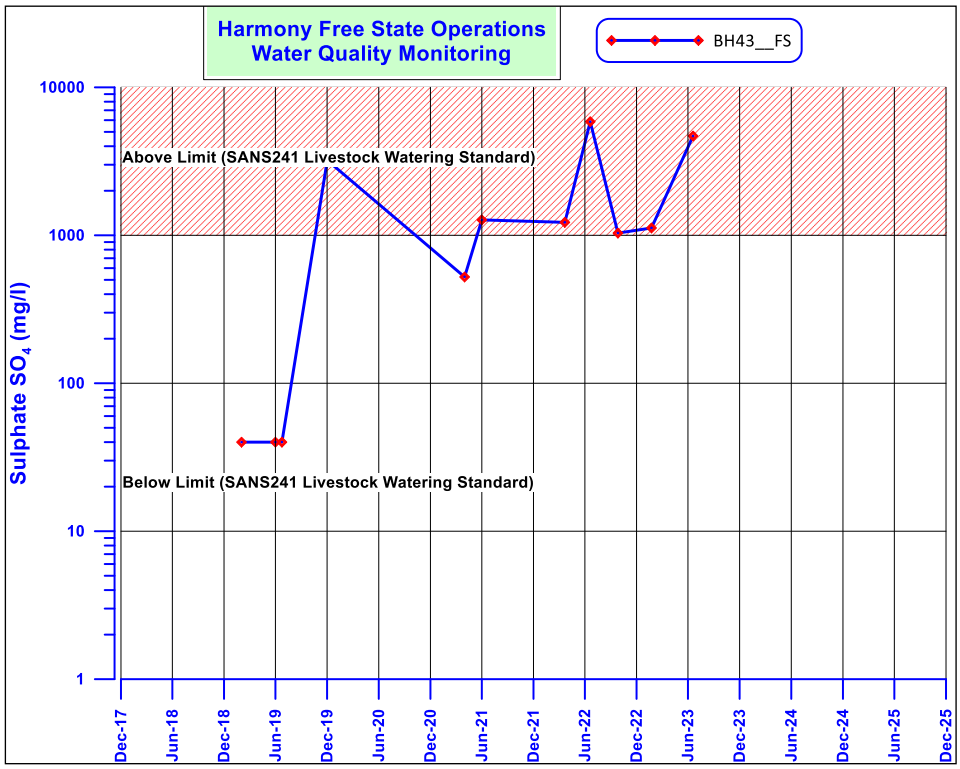

Harmony Free State Operations
Water Quality Monitoring
BH3A
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

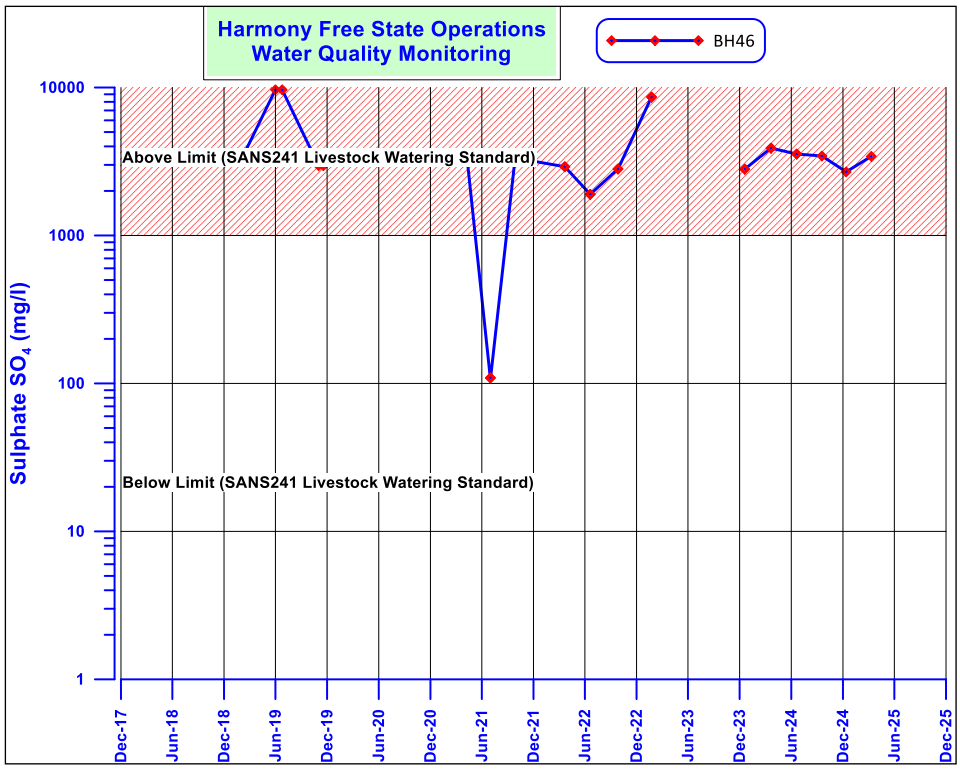

Harmony Free State Operations
Water Quality Monitoring
BH3B
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

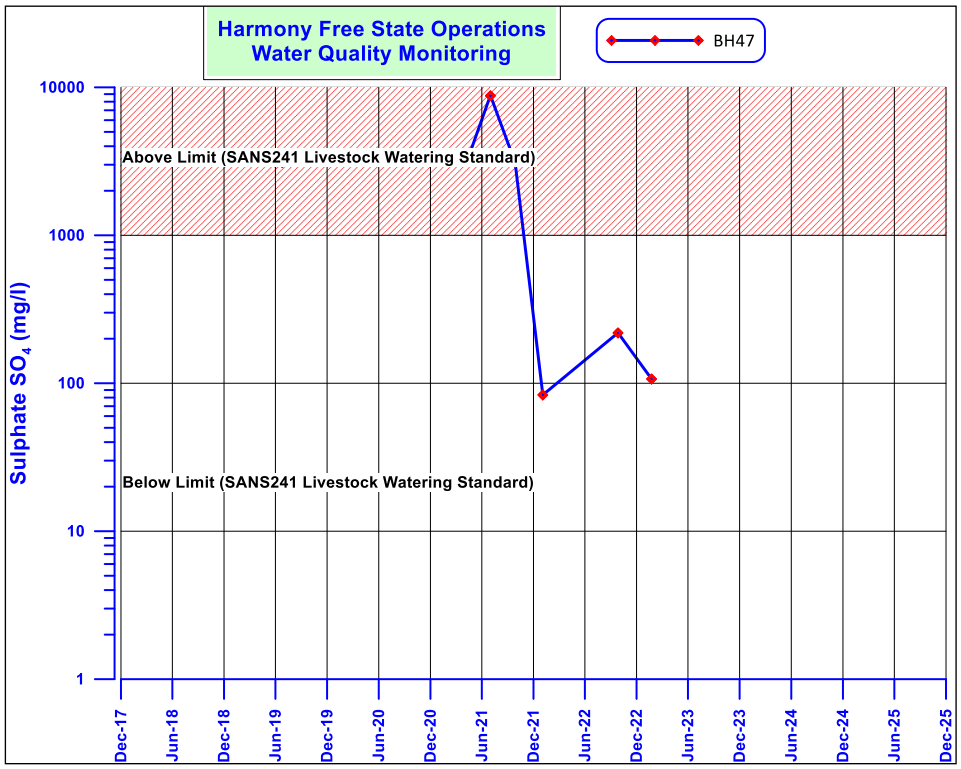

Harmony Free State Operations
Water Quality Monitoring
BH4
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

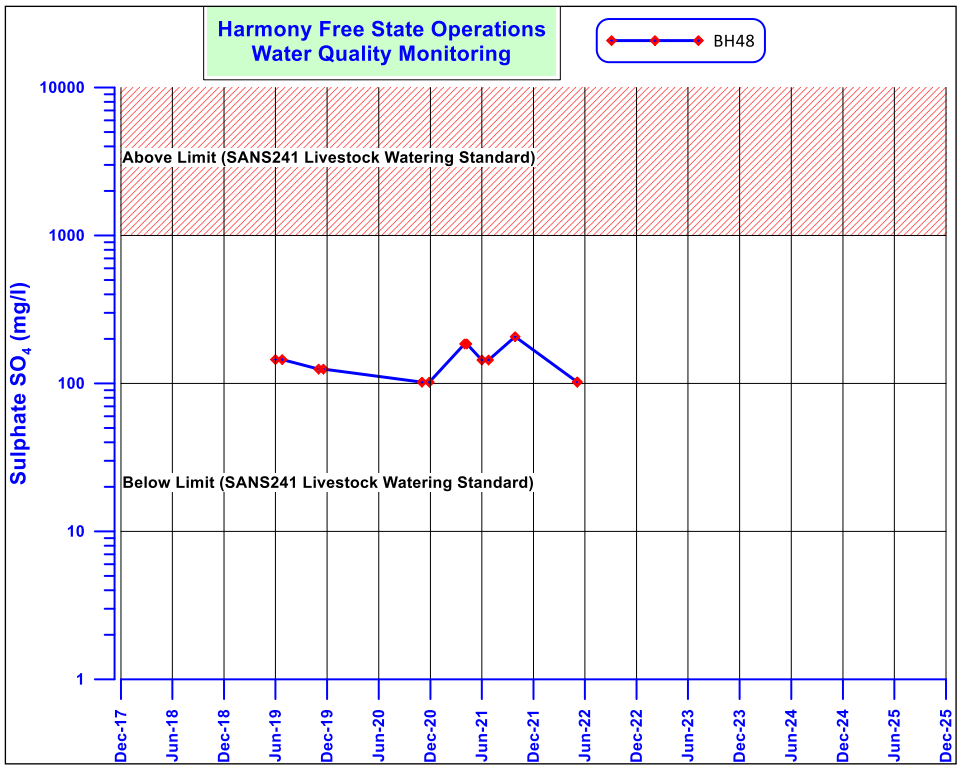

Harmony Free State Operations
Water Quality Monitoring
BH41
Sulphate SO_4 (mg/l)
10000
1000
100
10
1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

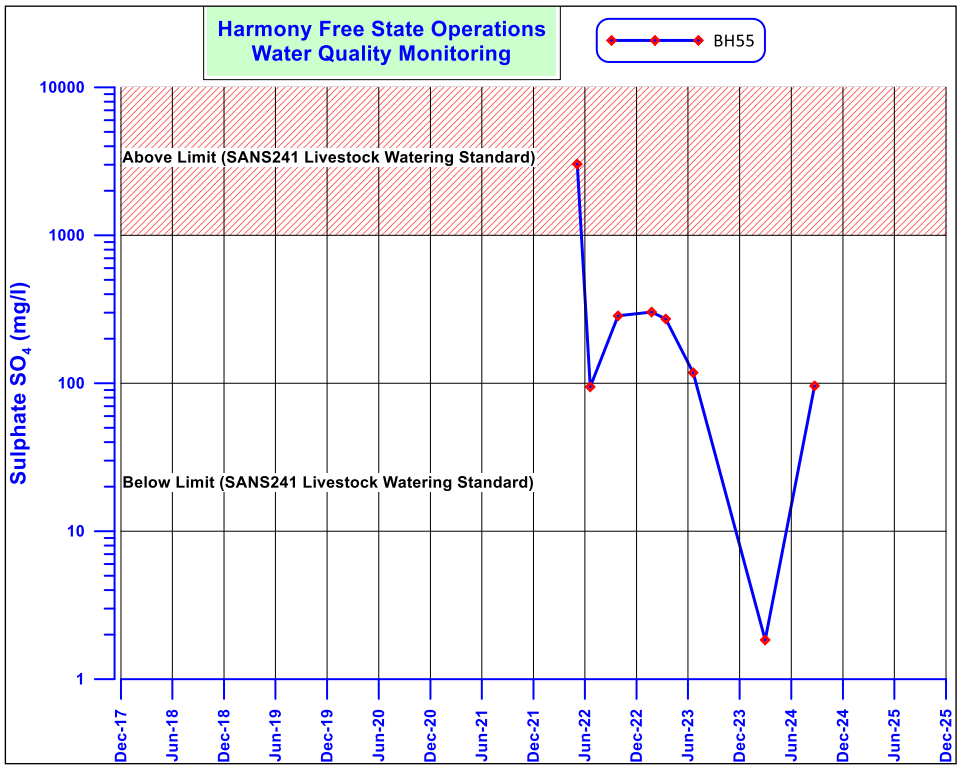

Harmony Free State Operations
Water Quality Monitoring
BH43
Sulphate SO_4 (mg/l)
10000
1000
100
10
1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

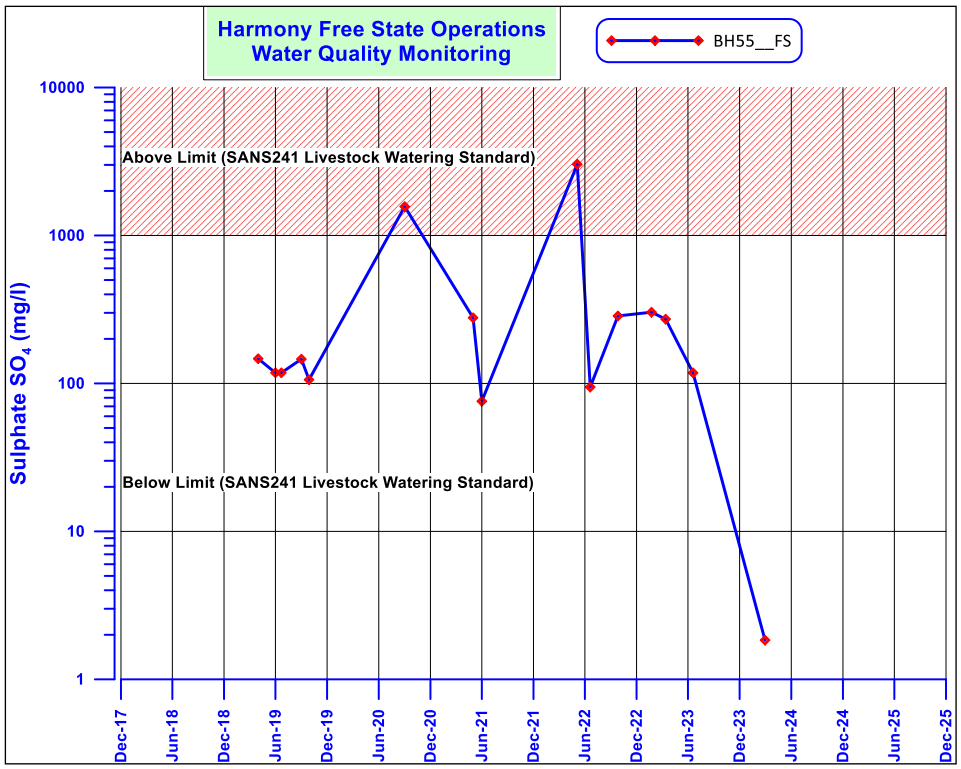

Harmony Free State Operations
Water Quality Monitoring
BH43__FS
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

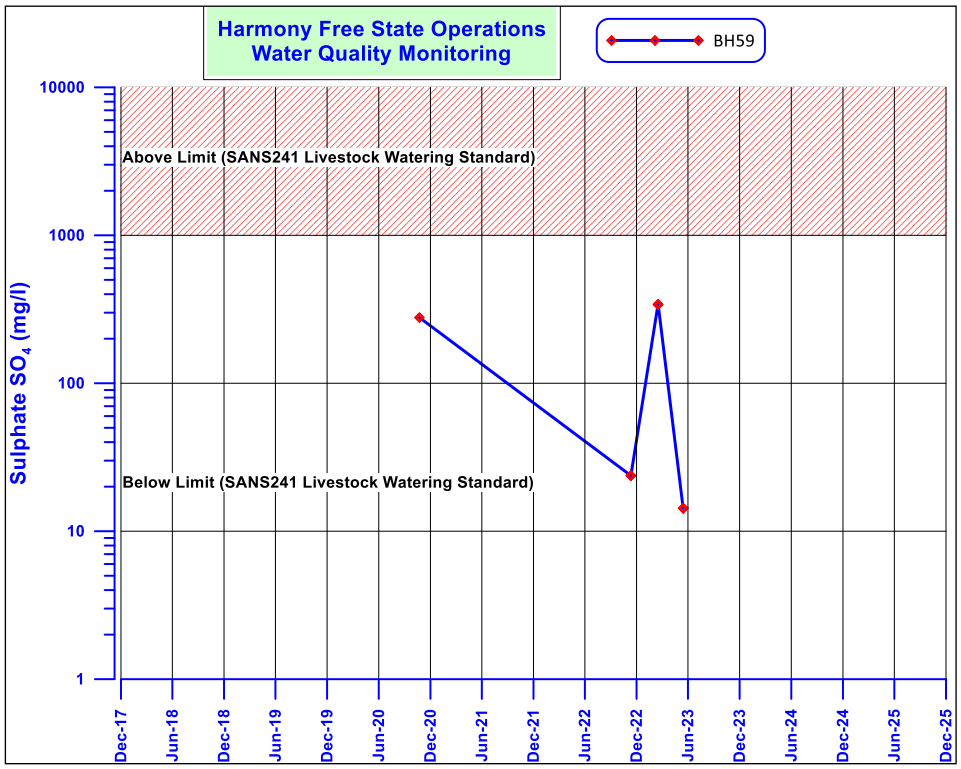

Harmony Free State Operations
Water Quality Monitoring
BH46
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

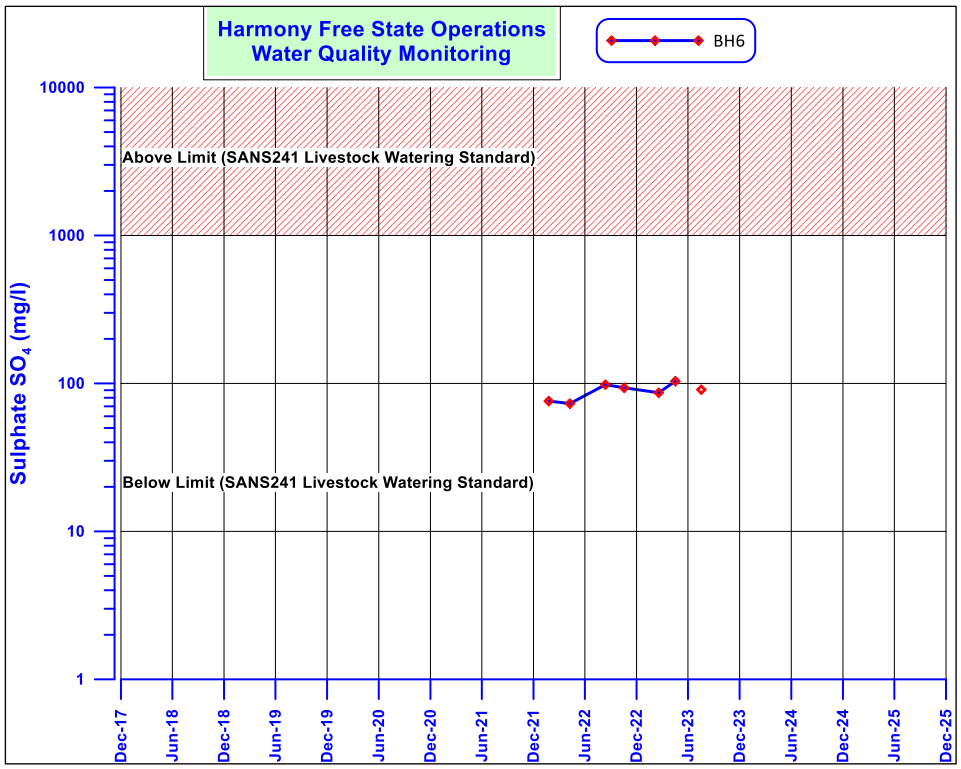

Harmony Free State Operations
Water Quality Monitoring
BH47
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

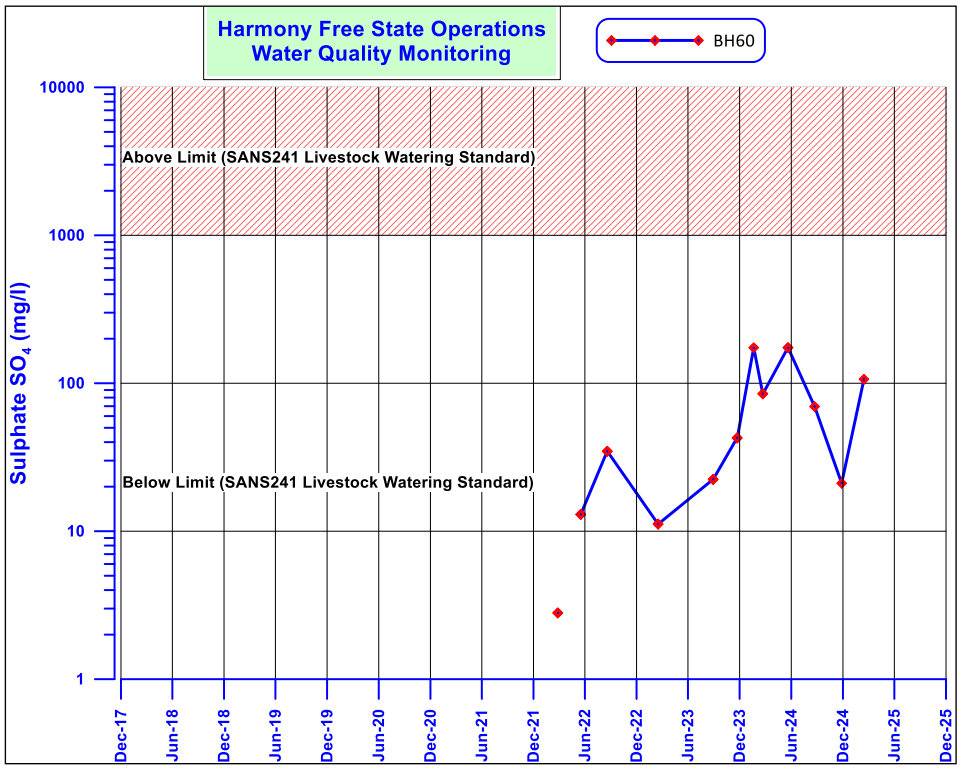

Harmony Free State Operations
Water Quality Monitoring
BH48
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

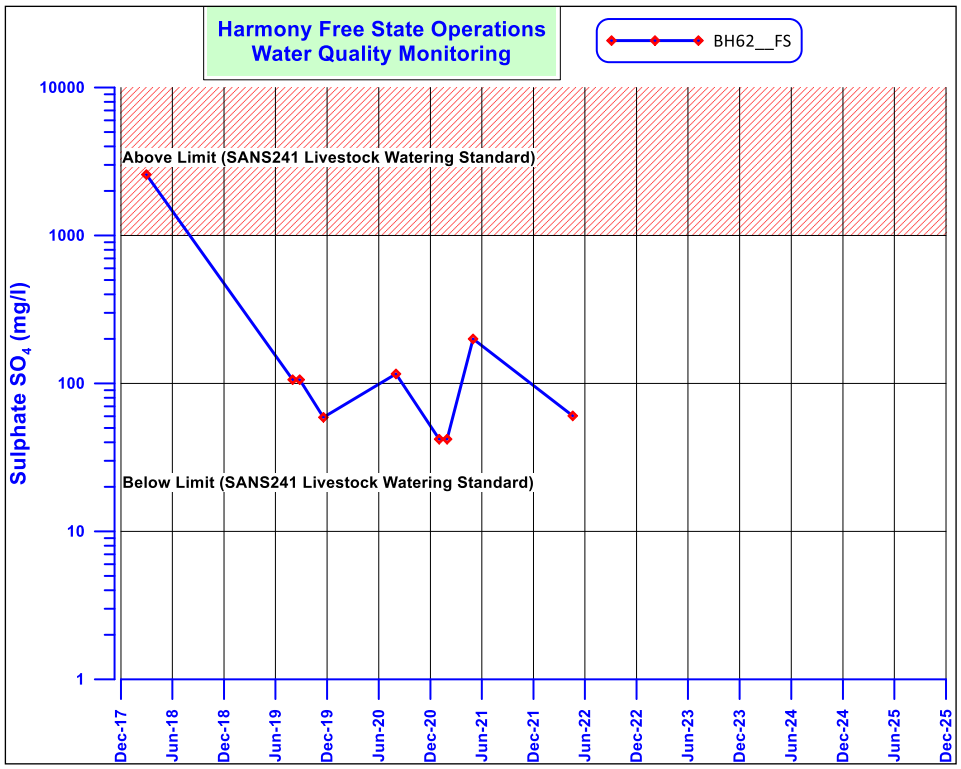

Harmony Free State Operations
Water Quality Monitoring
BH55
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

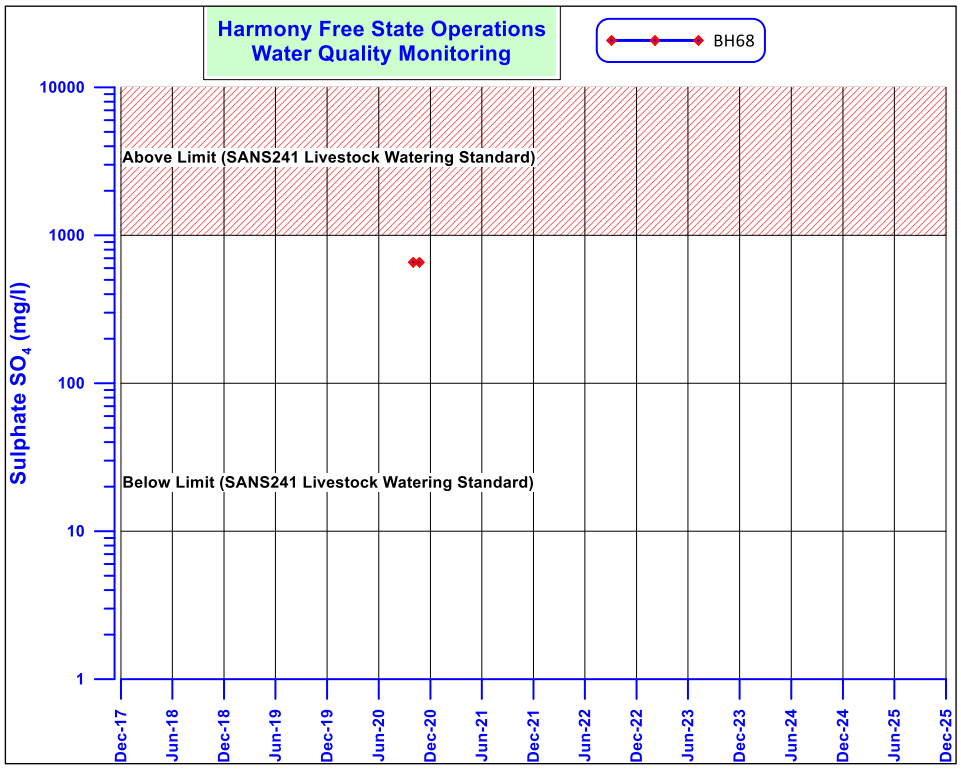

Harmony Free State Operations
Water Quality Monitoring
BH55__FS
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

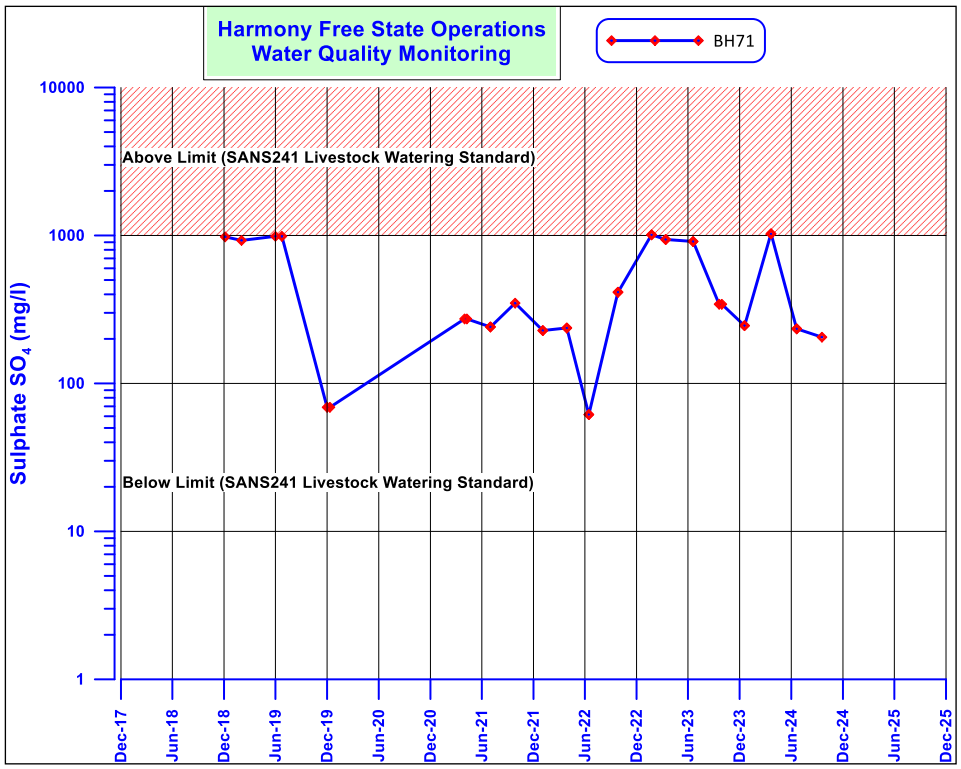

Harmony Free State Operations
Water Quality Monitoring
BH59
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

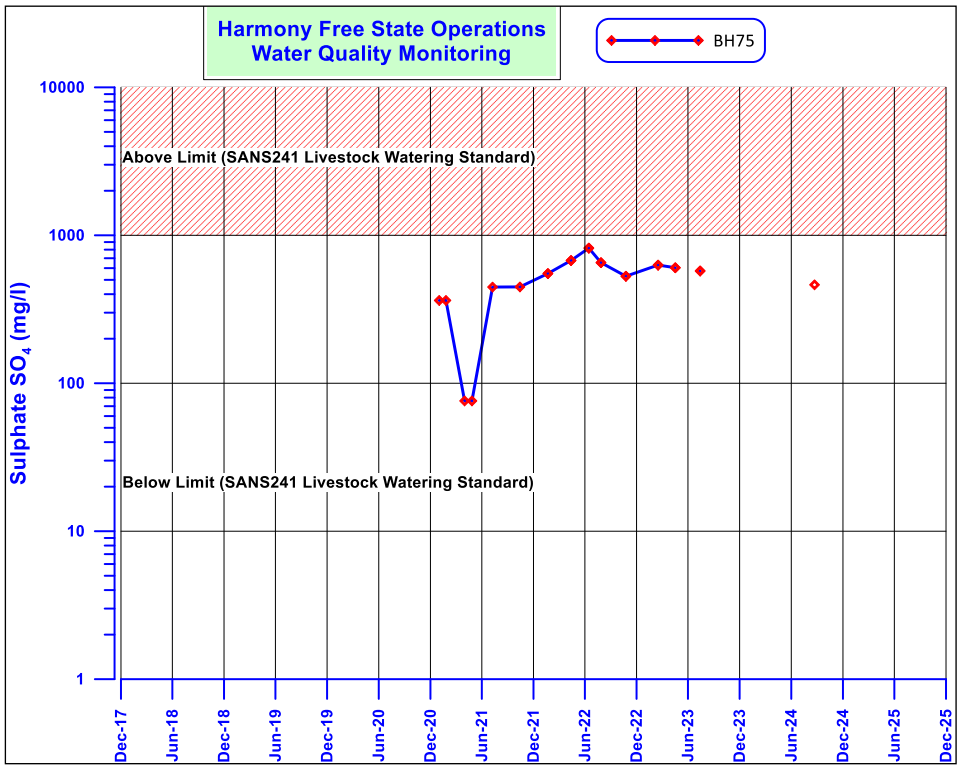

Harmony Free State Operations
Water Quality Monitoring
BH6
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

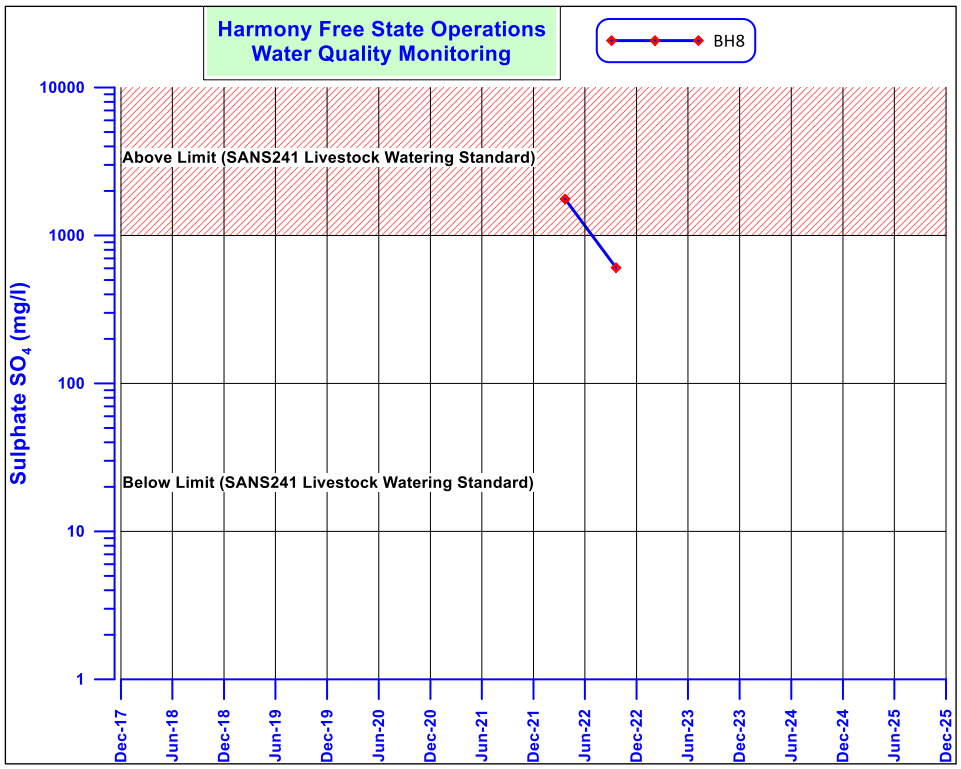

Harmony Free State Operations
Water Quality Monitoring
BH60
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

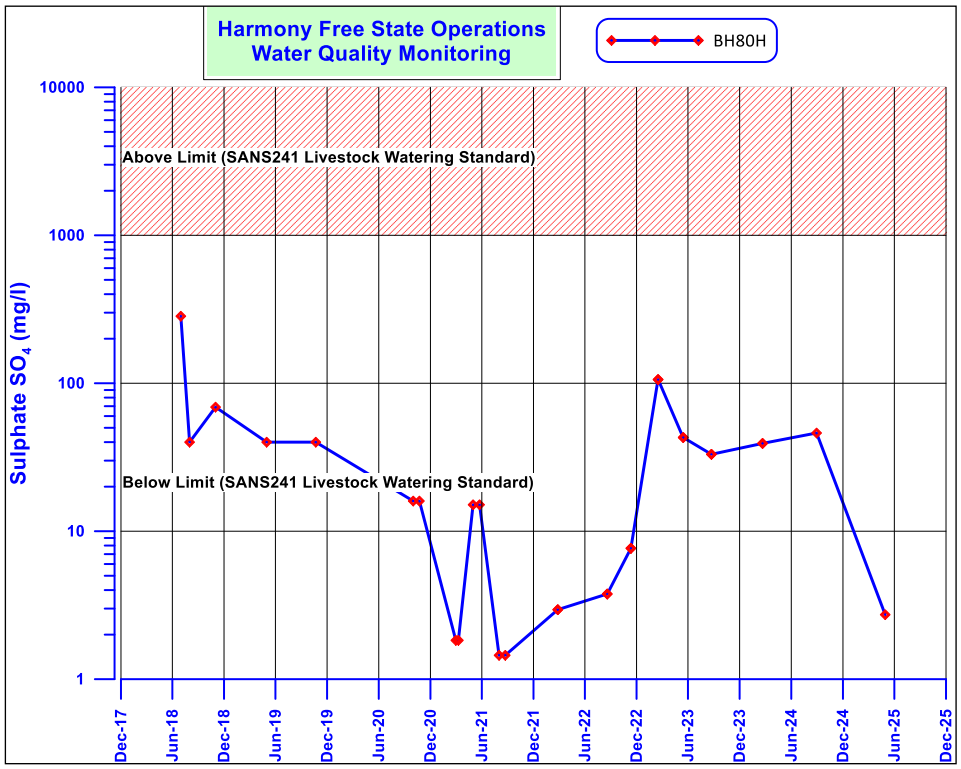

Harmony Free State Operations
Water Quality Monitoring
BH62__FS
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

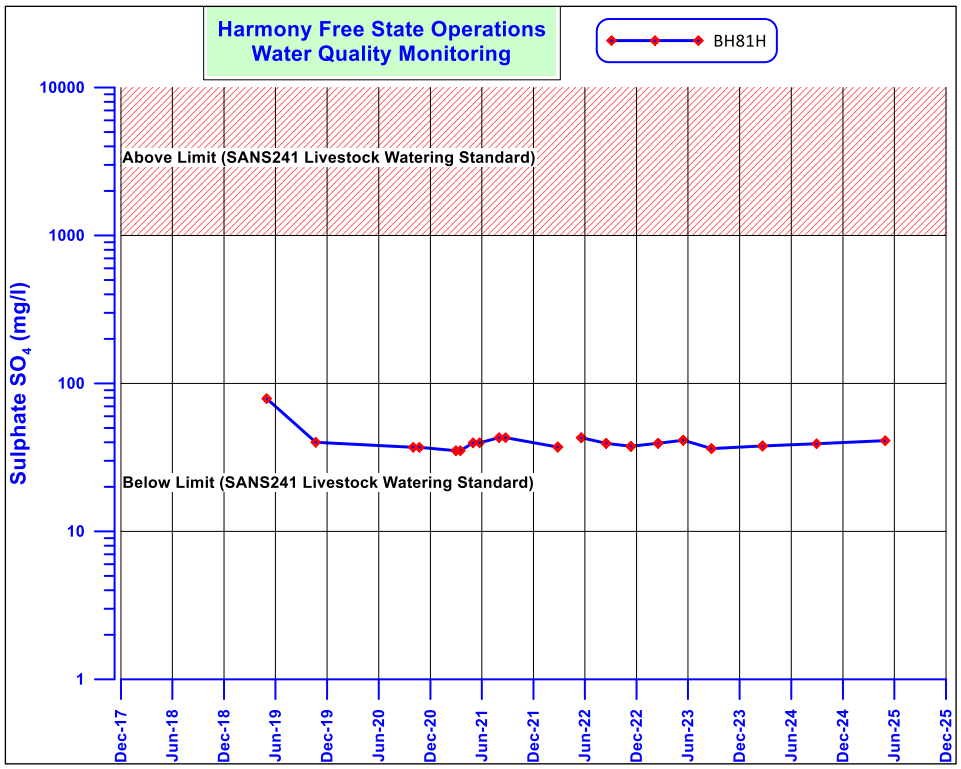

Harmony Free State Operations
Water Quality Monitoring
BH68
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

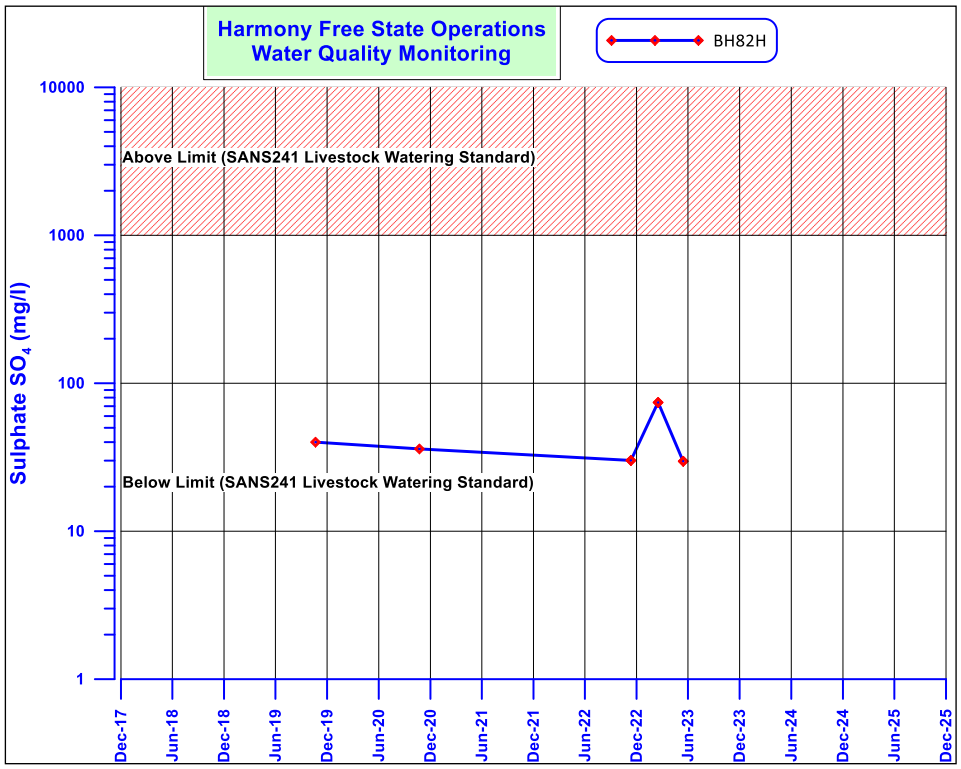

Harmony Free State Operations
Water Quality Monitoring
BH71
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

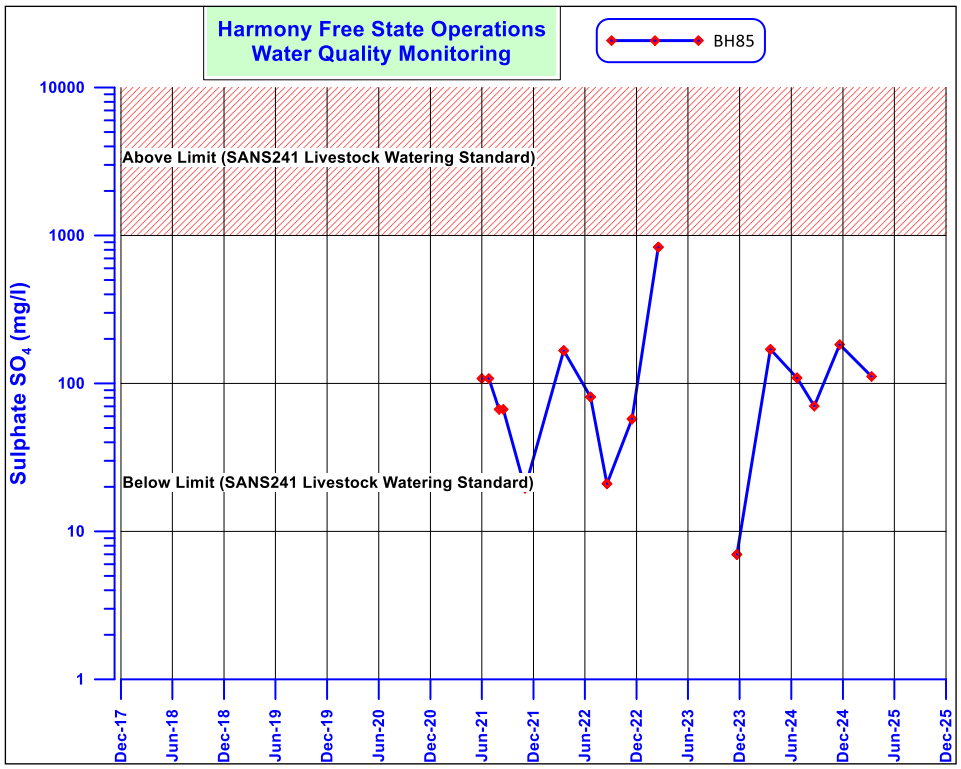

Harmony Free State Operations
Water Quality Monitoring
BH75
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

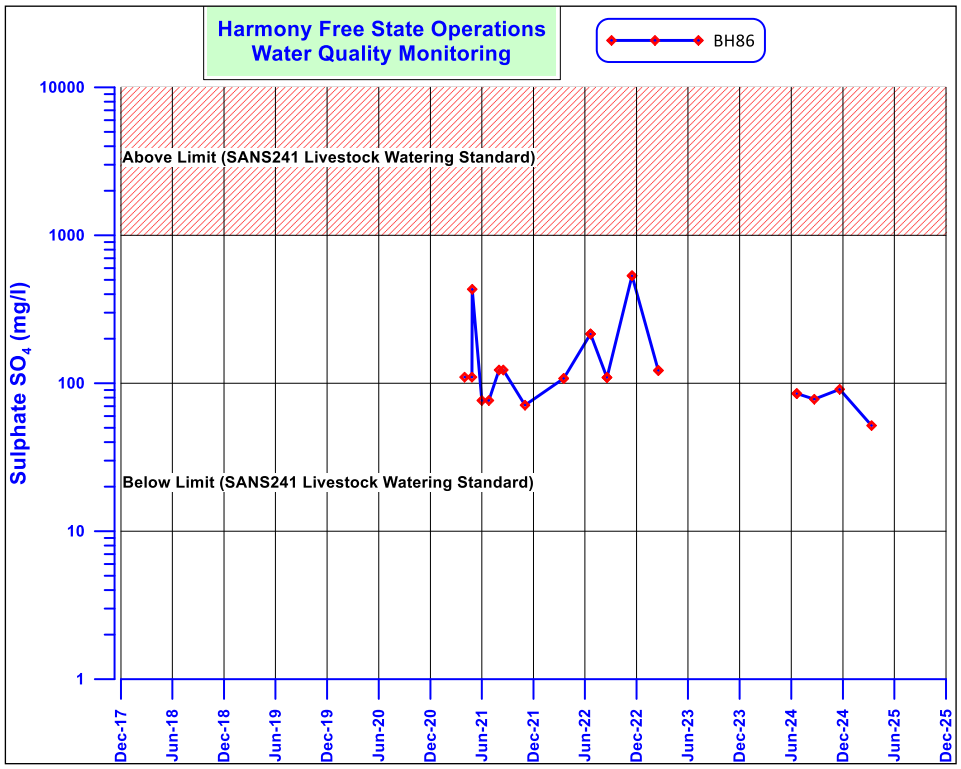

Harmony Free State Operations
Water Quality Monitoring
BH8
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

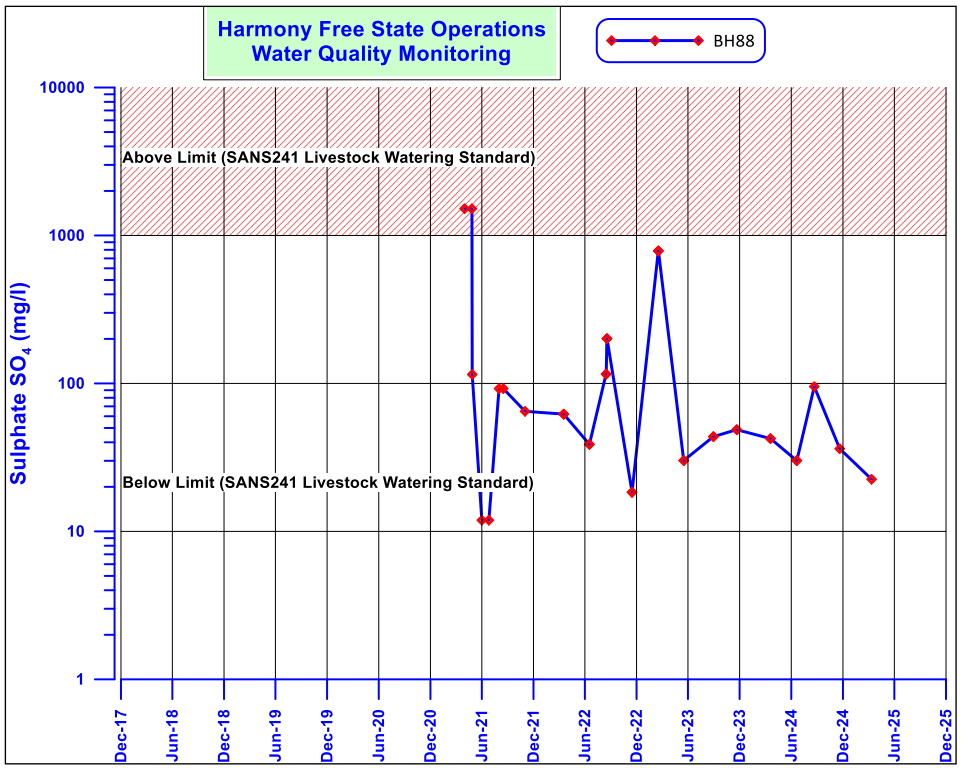

Harmony Free State Operations
Water Quality Monitoring
BH80H
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

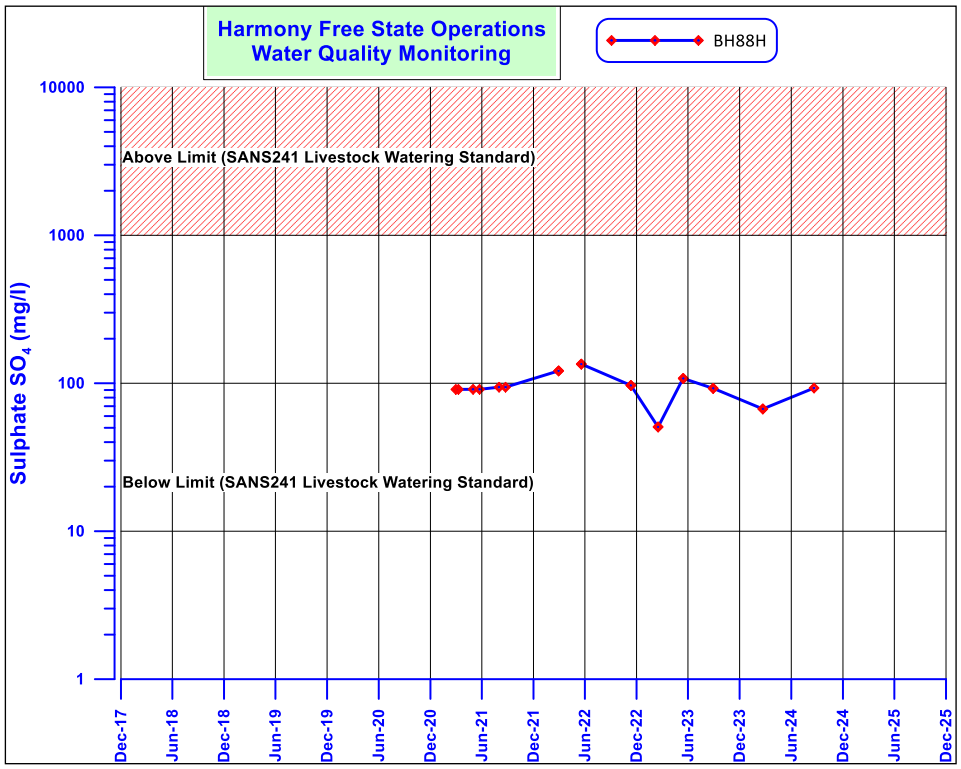

Harmony Free State Operations
Water Quality Monitoring
BH81H
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

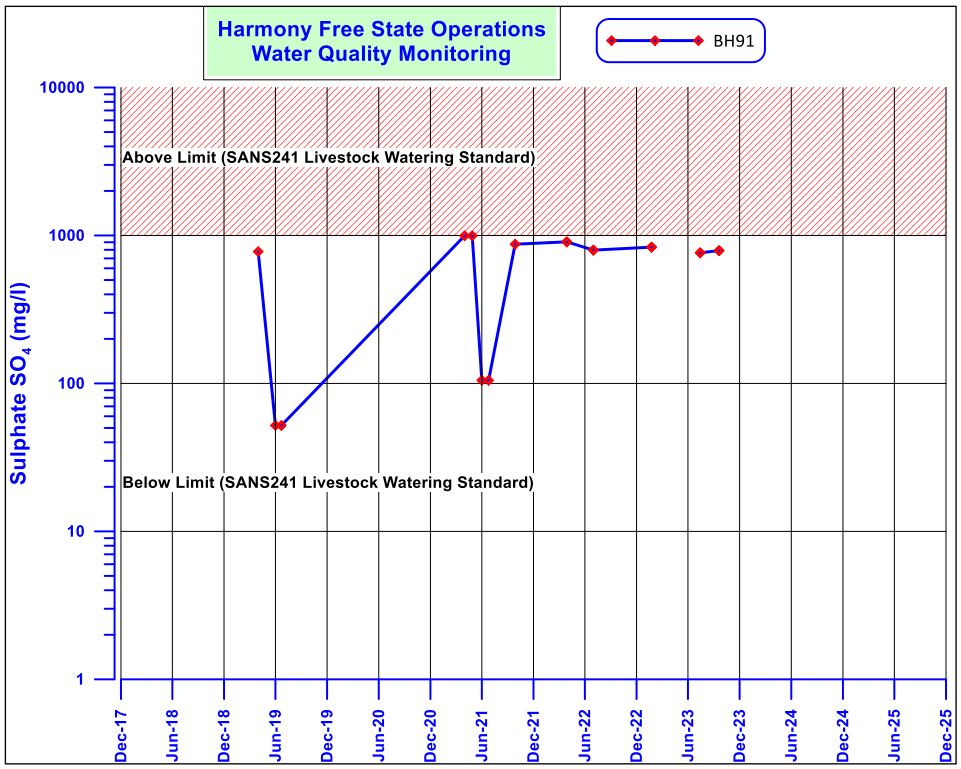

Harmony Free State Operations
Water Quality Monitoring
BH82H
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

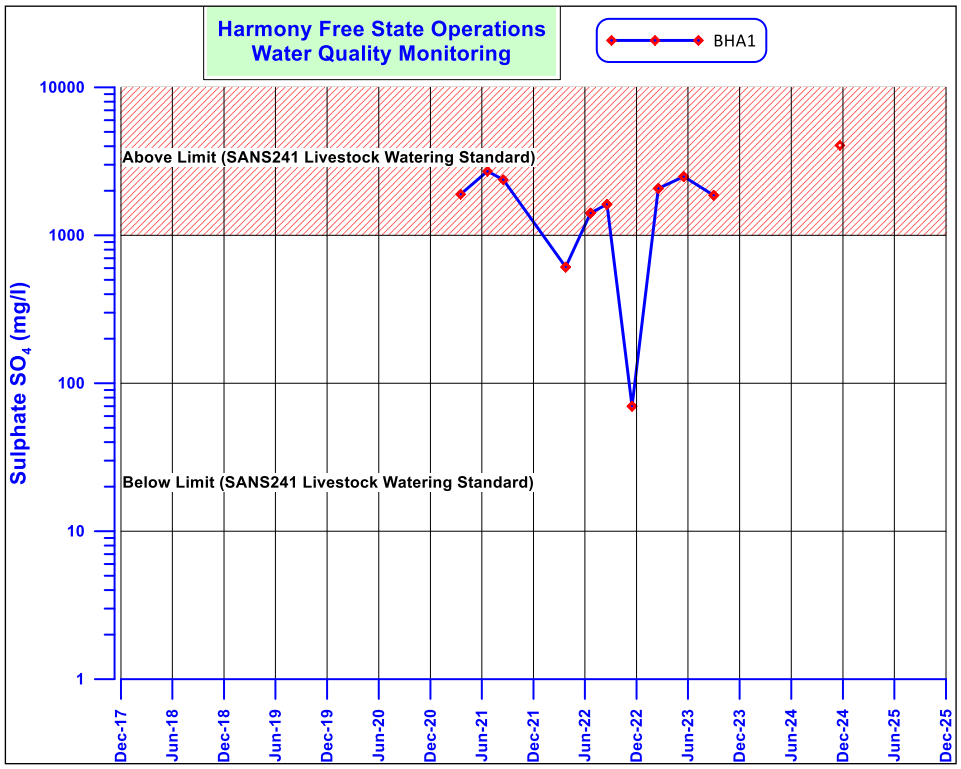

Harmony Free State Operations
Water Quality Monitoring
BH85
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

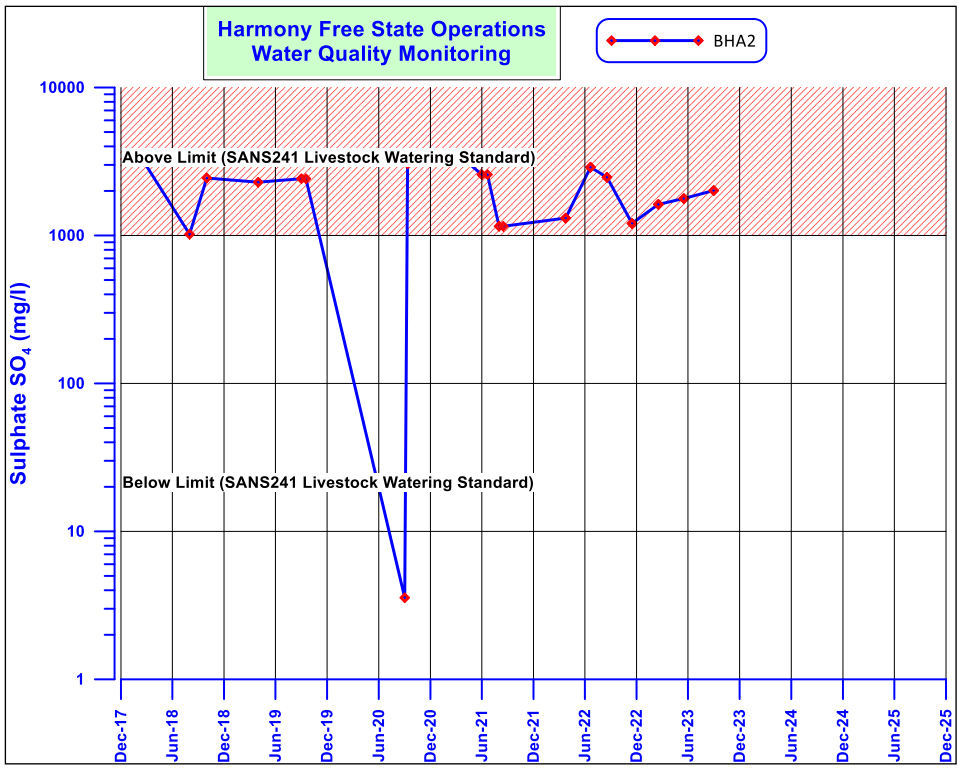

Harmony Free State Operations
Water Quality Monitoring
BH86
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

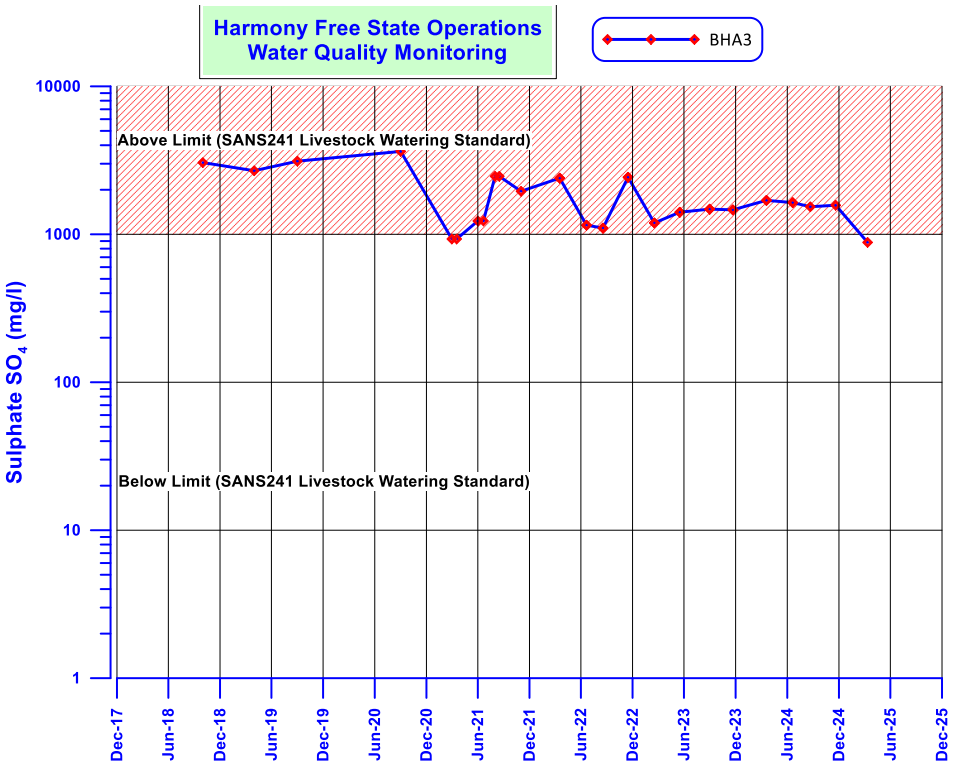

Harmony Free State Operations
Water Quality Monitoring
BH88
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

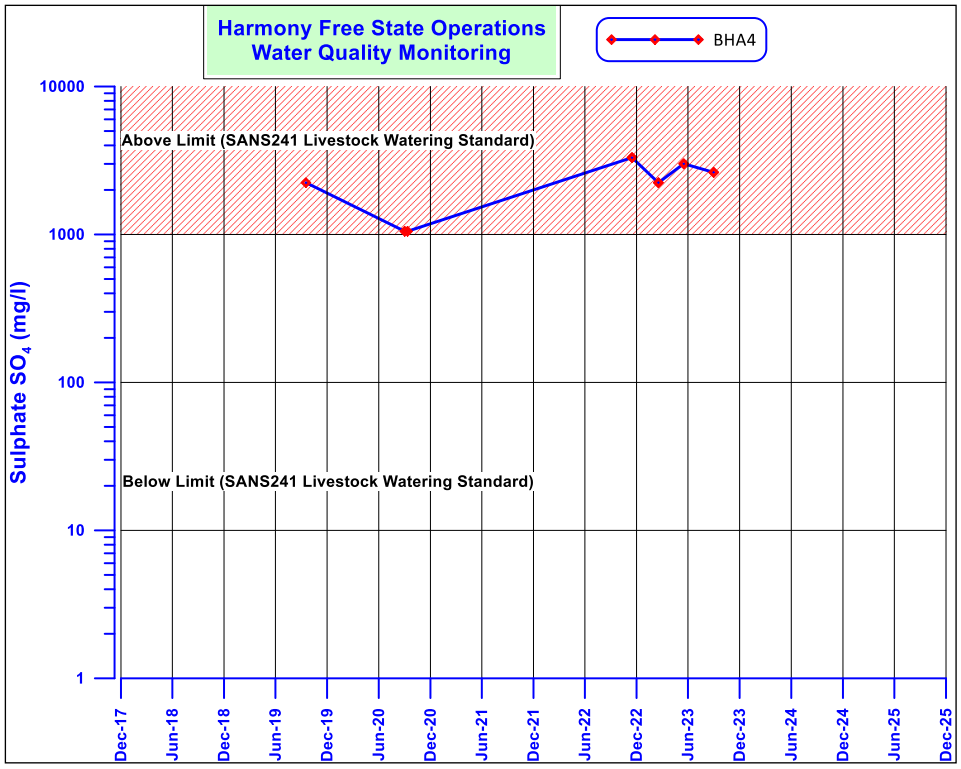

Harmony Free State Operations
Water Quality Monitoring
BH88H
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

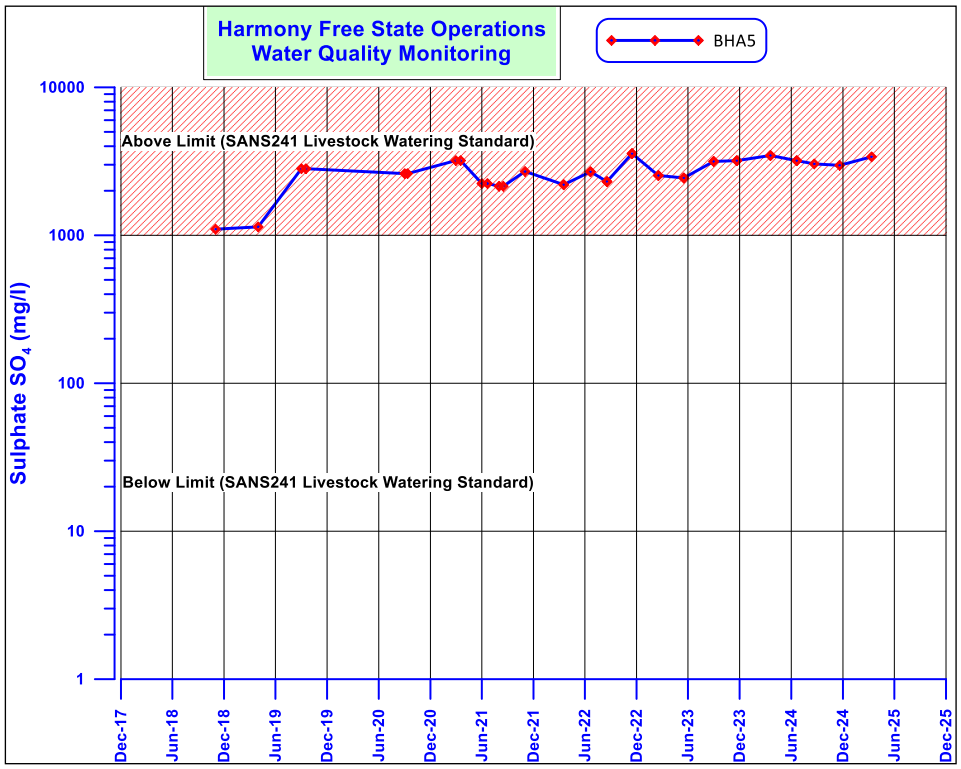

Harmony Free State Operations
Water Quality Monitoring
BH91
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

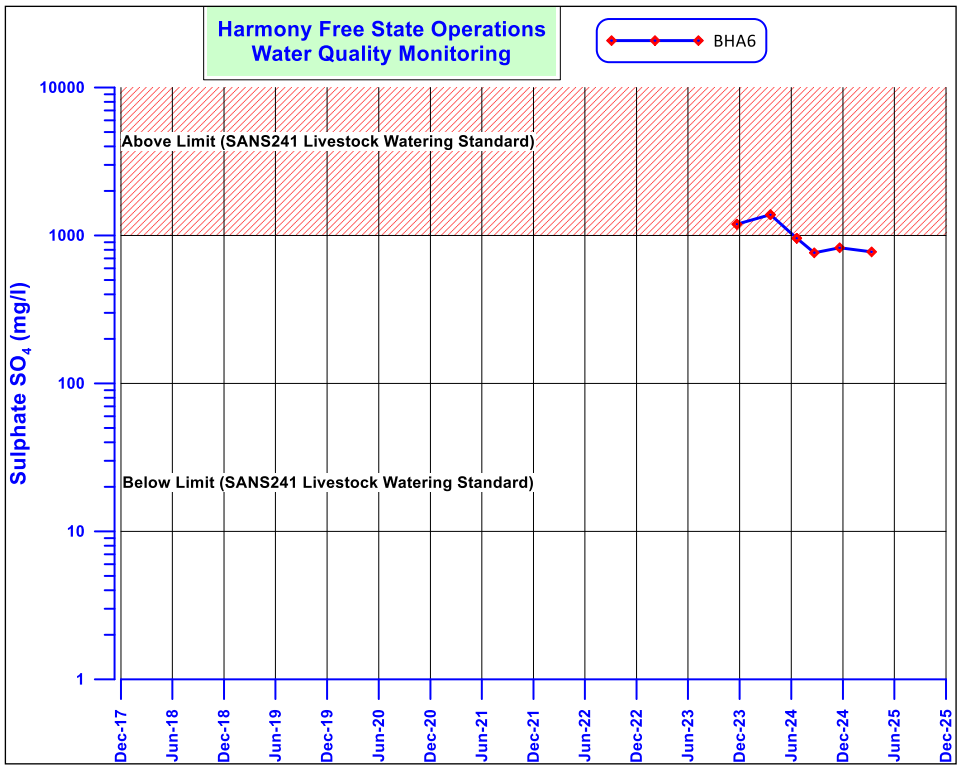

Harmony Free State Operations
Water Quality Monitoring
BHA1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

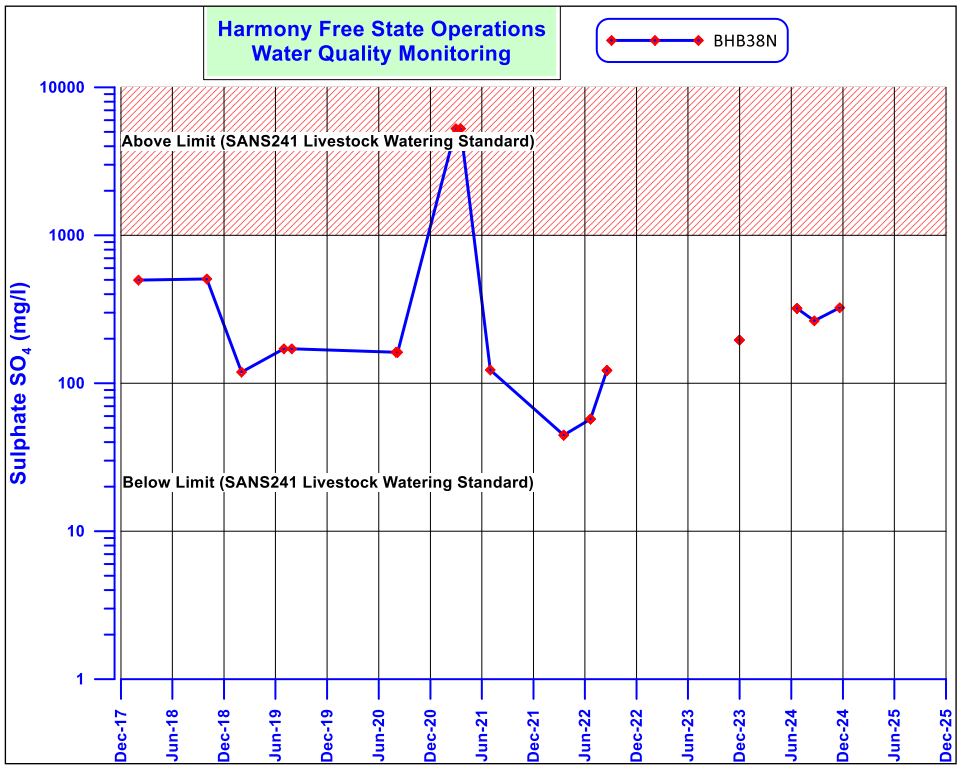

Harmony Free State Operations
Water Quality Monitoring
BHA2
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

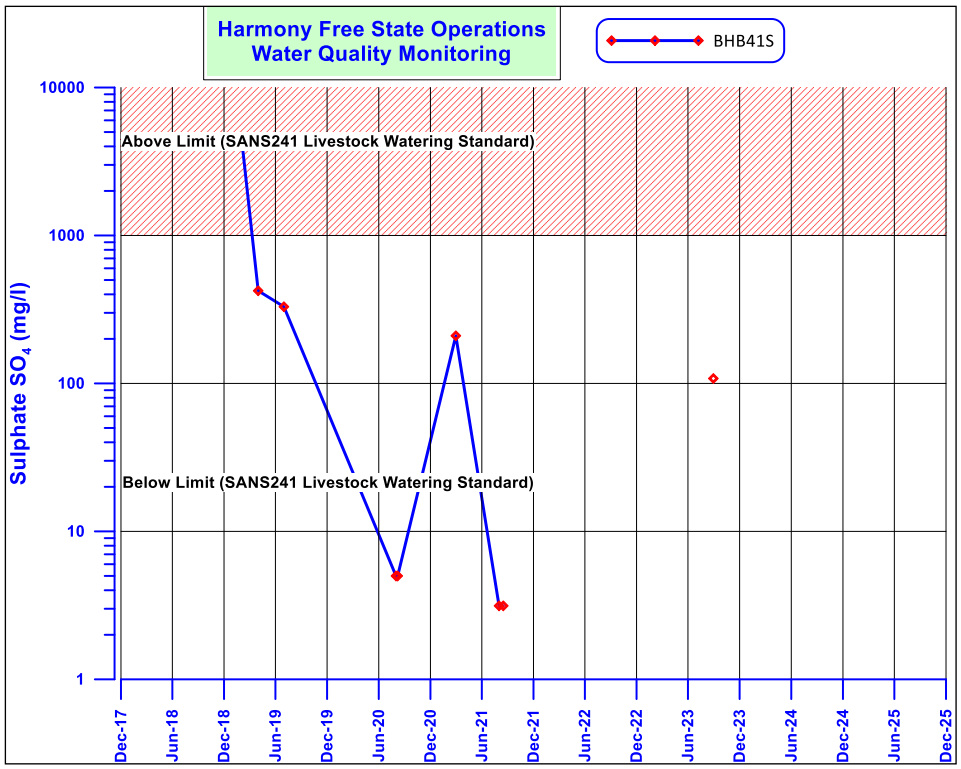

Harmony Free State Operations
Water Quality Monitoring
BHA3
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

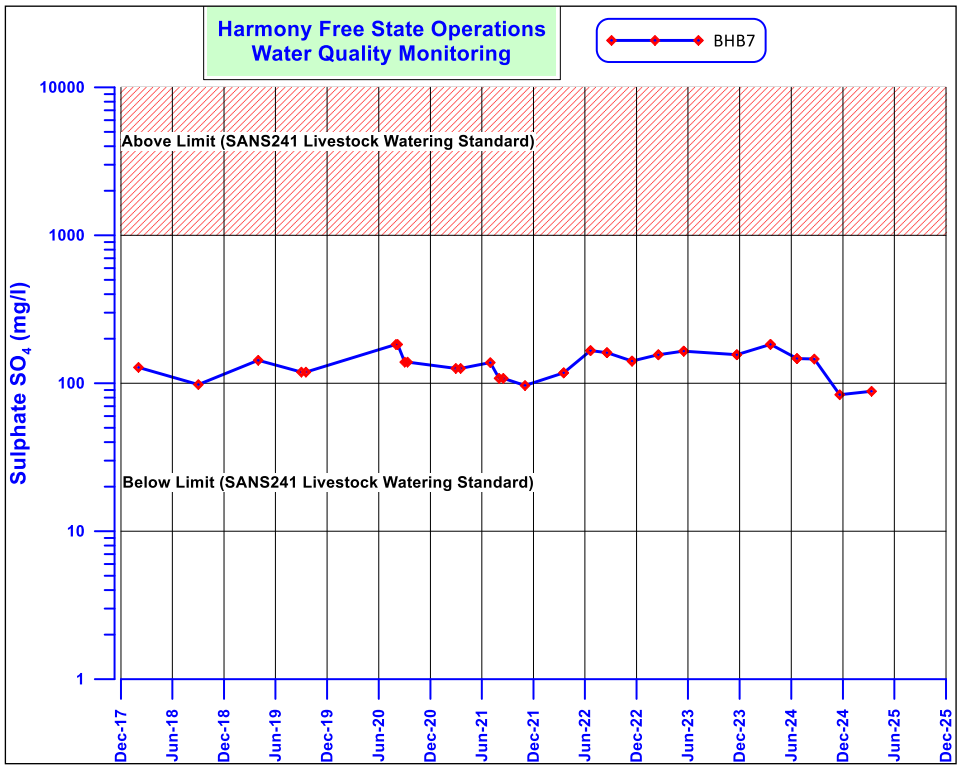

Harmony Free State Operations
Water Quality Monitoring
BHA4
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

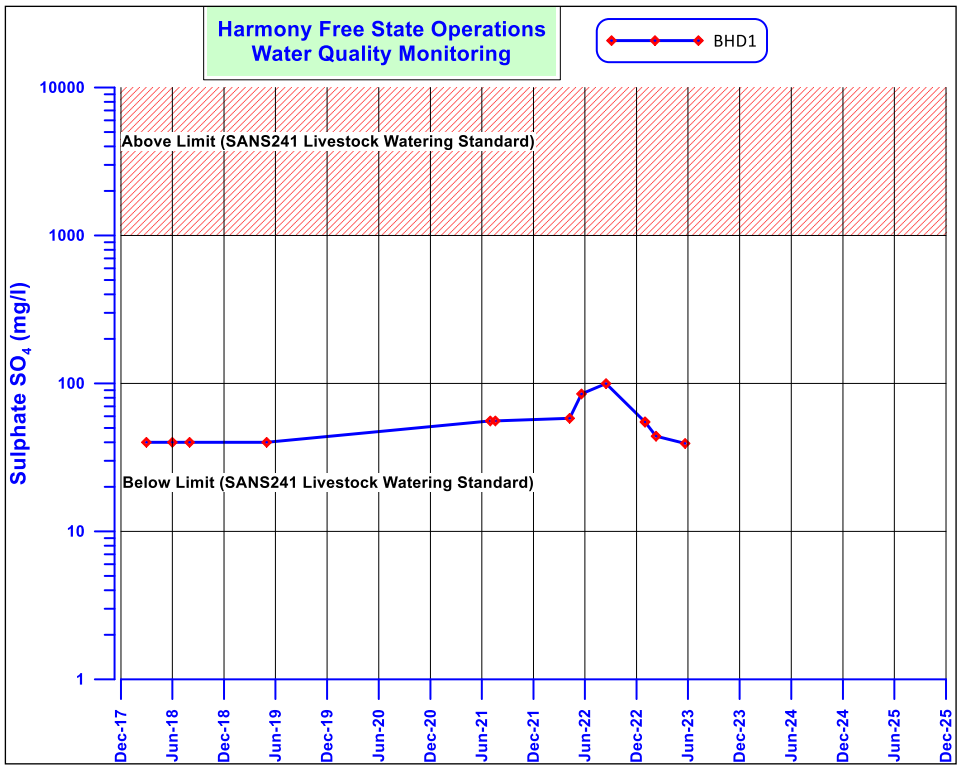

Harmony Free State Operations
Water Quality Monitoring
BHA5
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

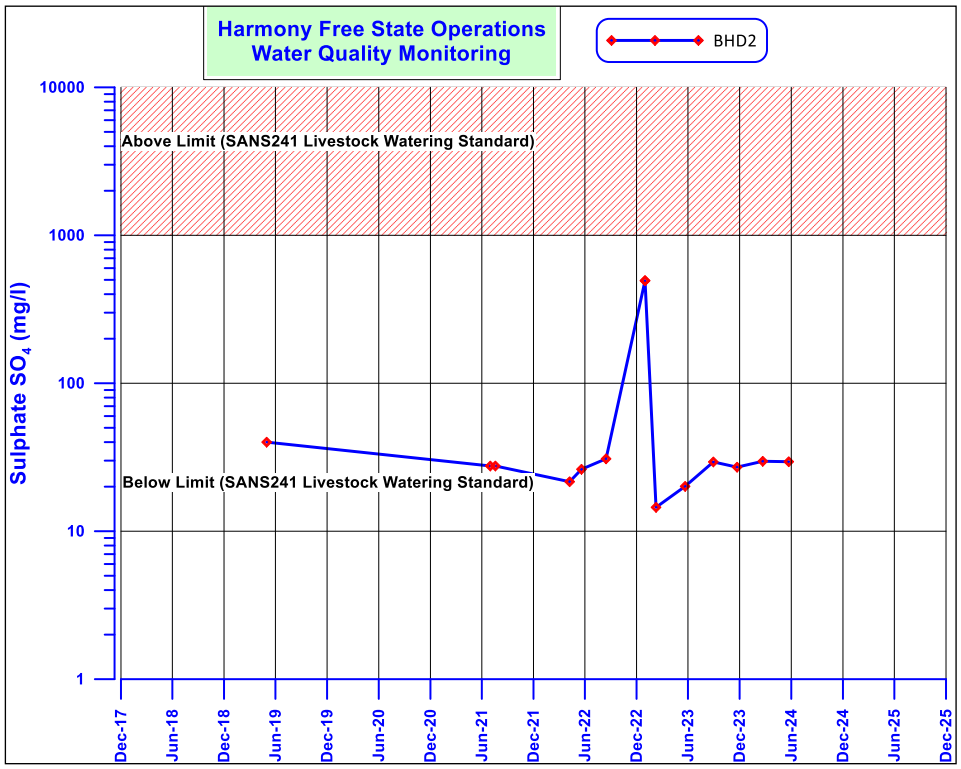

Harmony Free State Operations
Water Quality Monitoring
BHA6
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

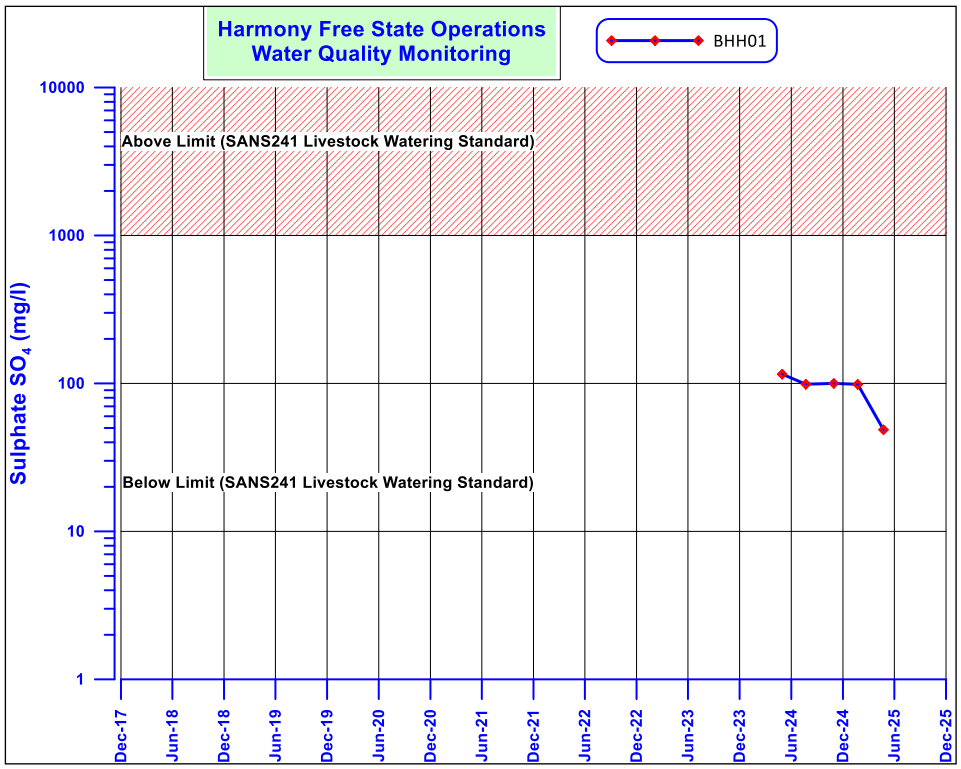

Harmony Free State Operations
Water Quality Monitoring
BHB38N
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

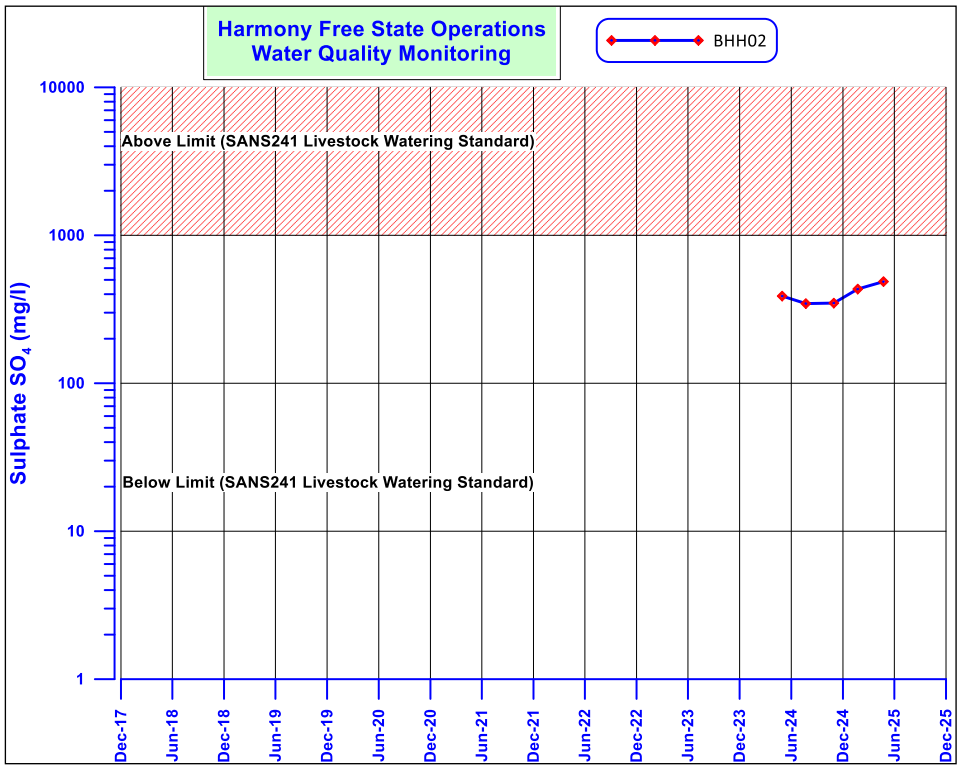

Harmony Free State Operations
Water Quality Monitoring
BHB41S
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

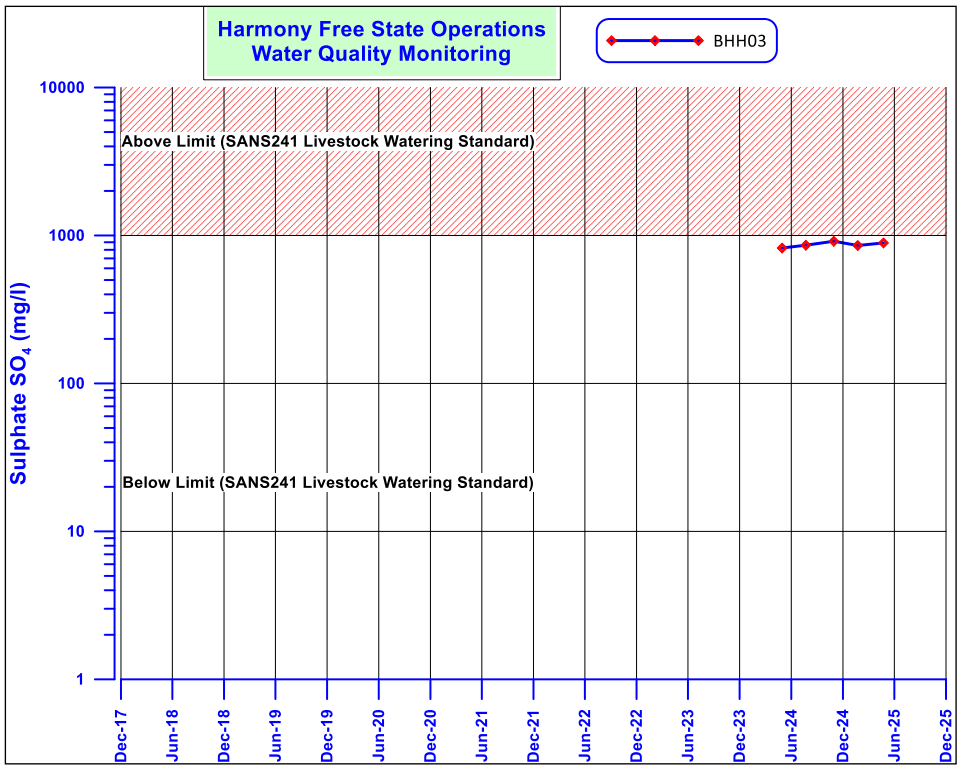

Harmony Free State Operations
Water Quality Monitoring
BHB7
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

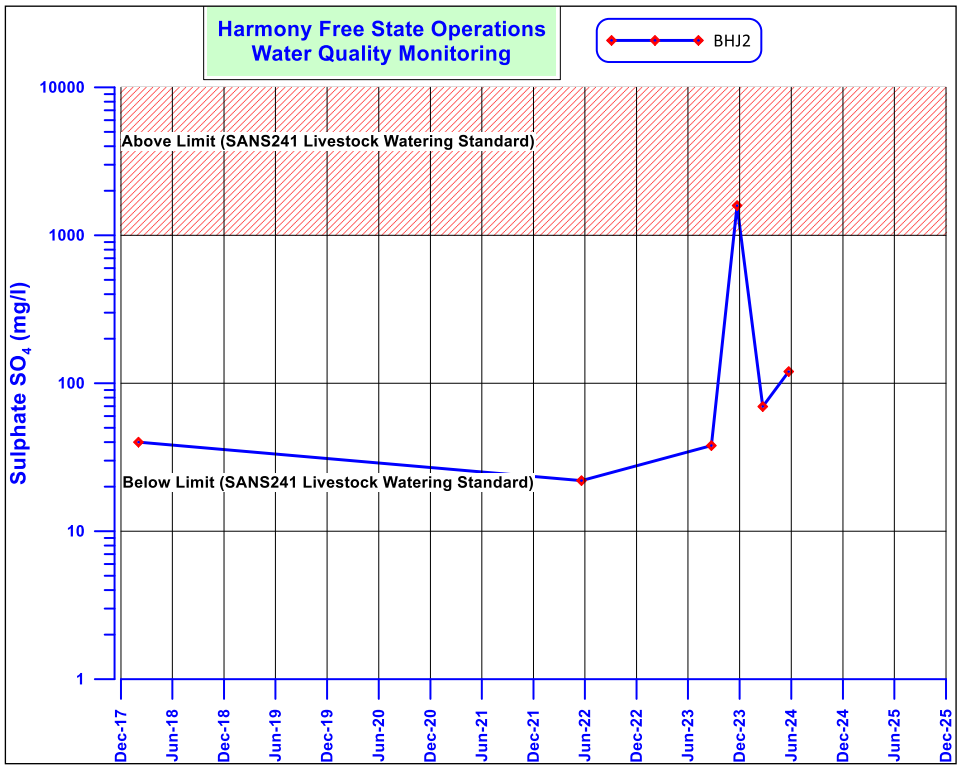

Harmony Free State Operations
Water Quality Monitoring
BHD1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

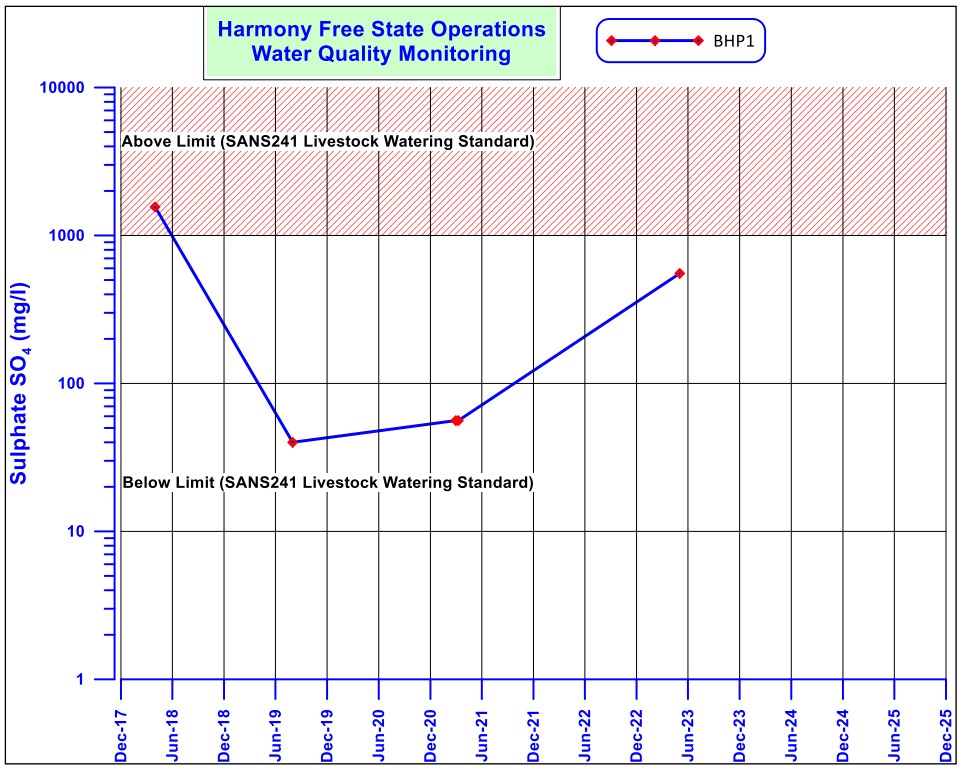

Harmony Free State Operations
Water Quality Monitoring
BHD2
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

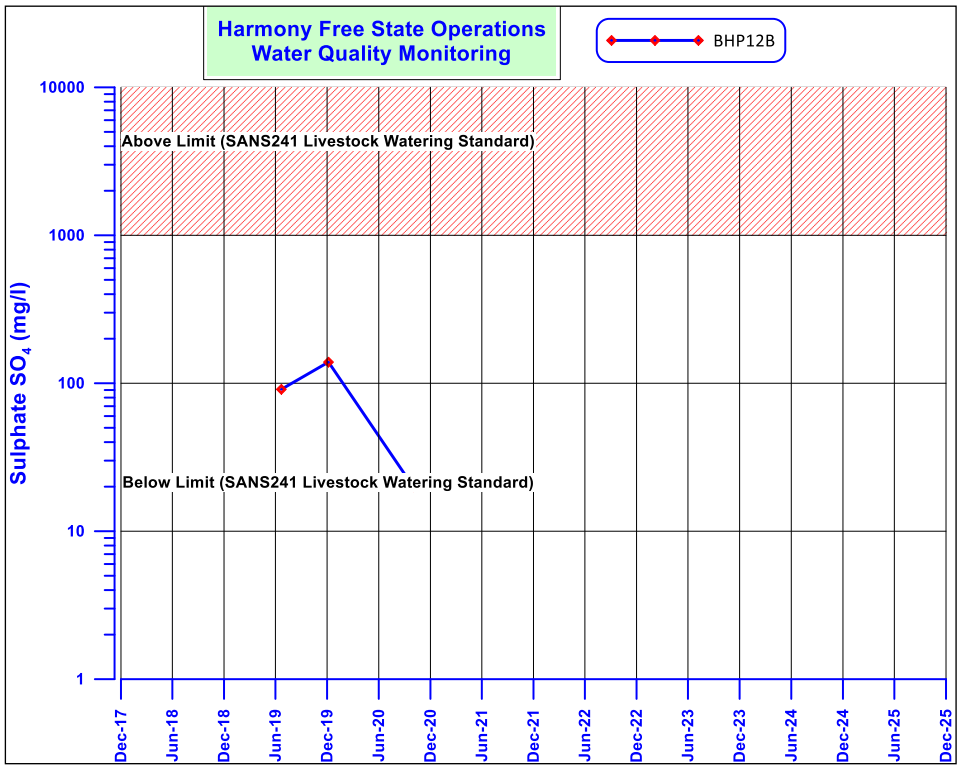

Harmony Free State Operations
Water Quality Monitoring
BHH01
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

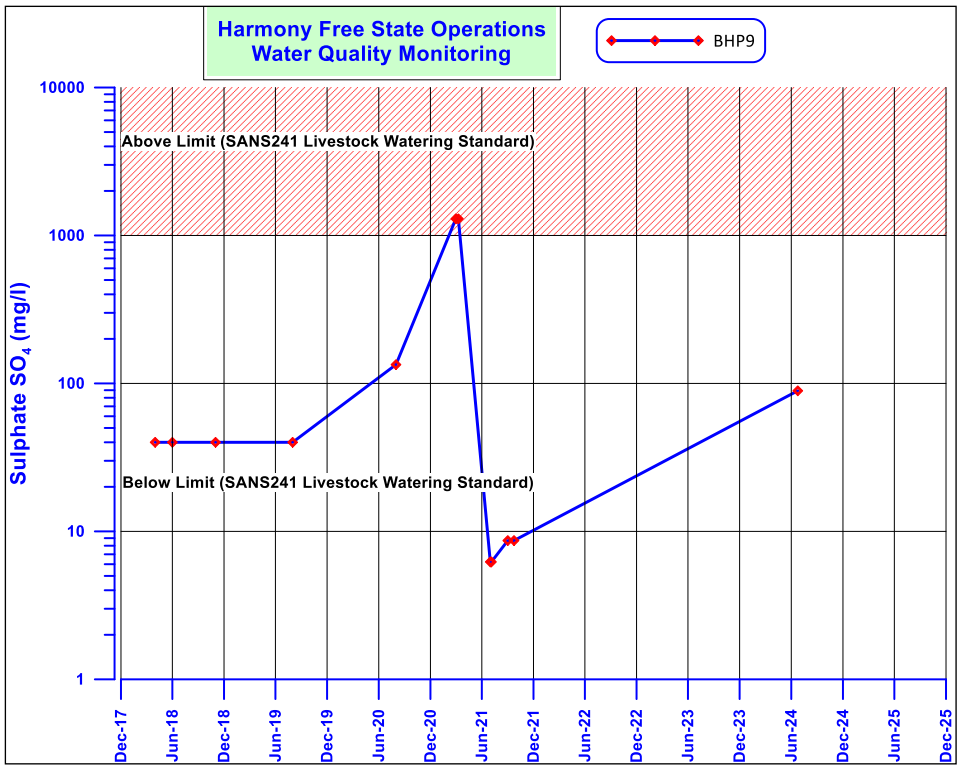

Harmony Free State Operations
Water Quality Monitoring
BHH02
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

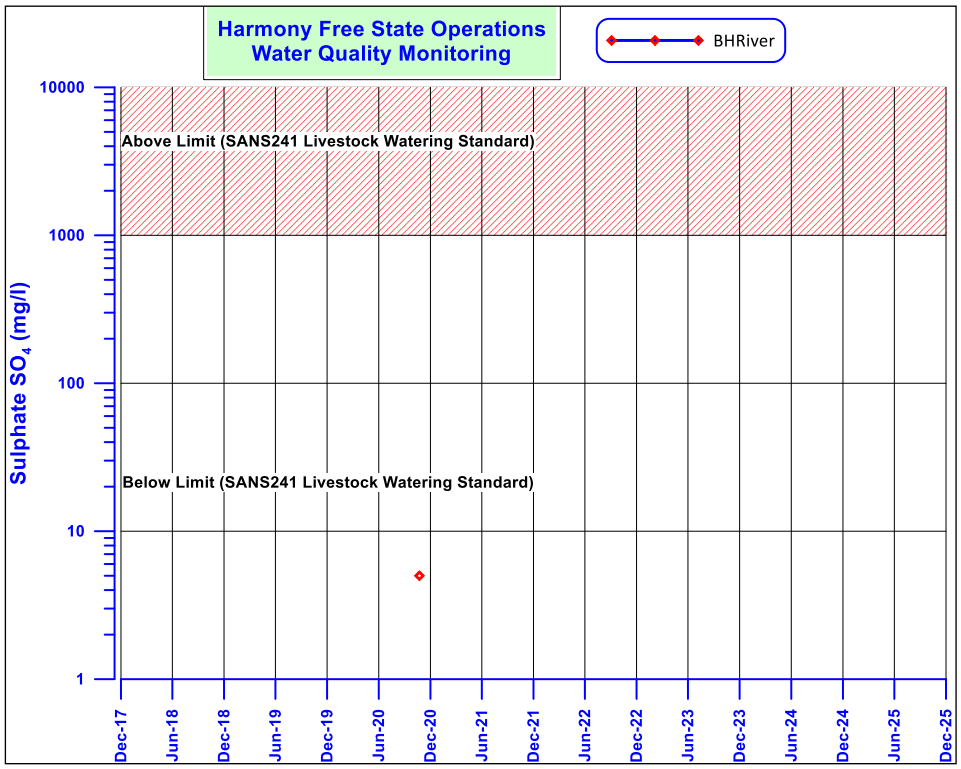

Harmony Free State Operations
Water Quality Monitoring
BHH03
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

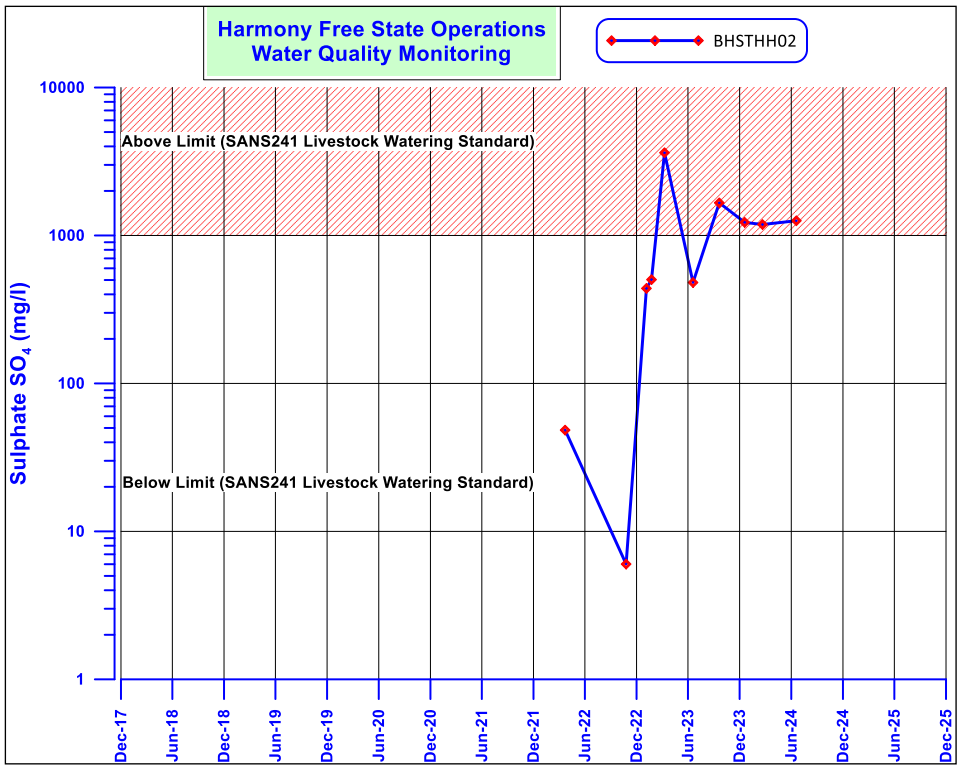

Harmony Free State Operations
Water Quality Monitoring
BHJ2
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

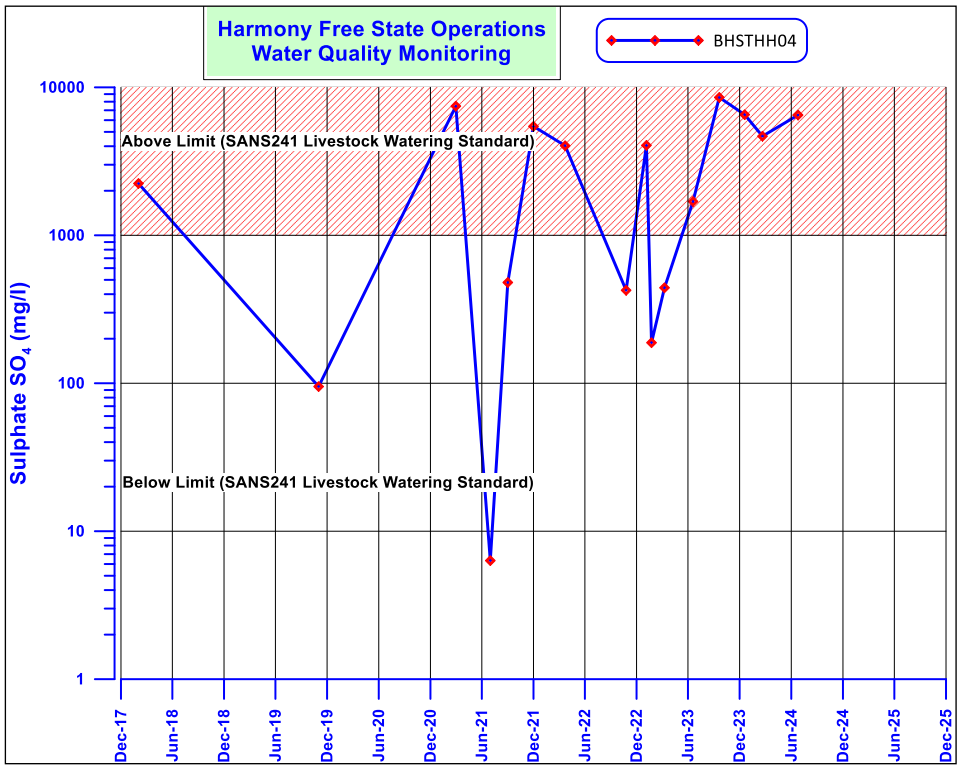

Harmony Free State Operations
Water Quality Monitoring
BHP1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

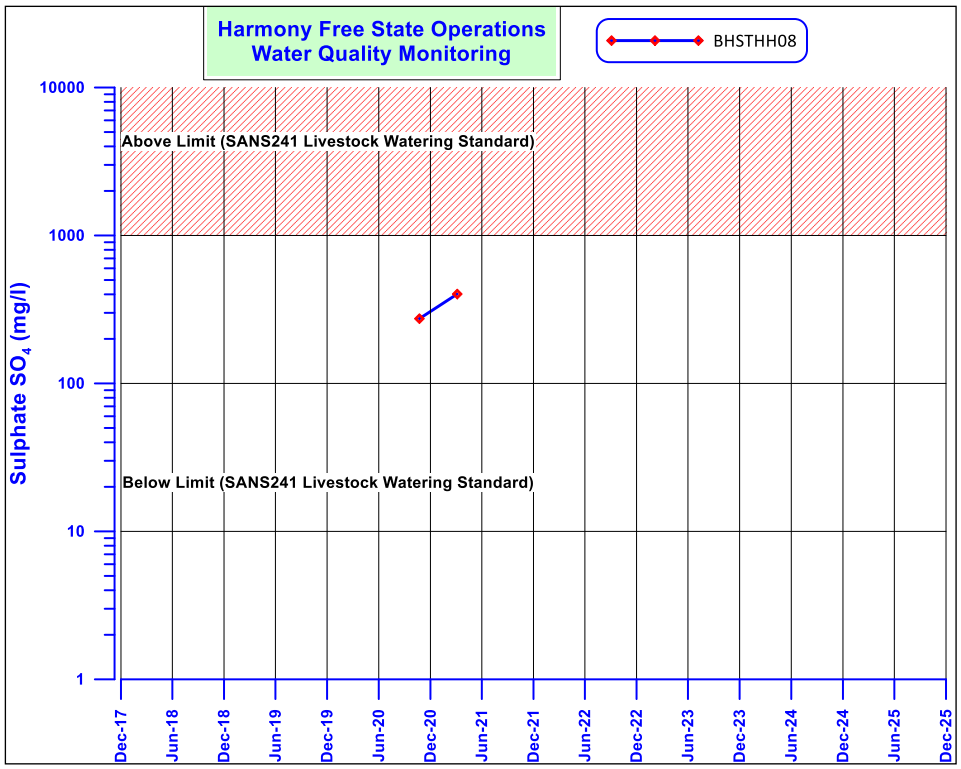

Harmony Free State Operations
Water Quality Monitoring
BHP12B
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

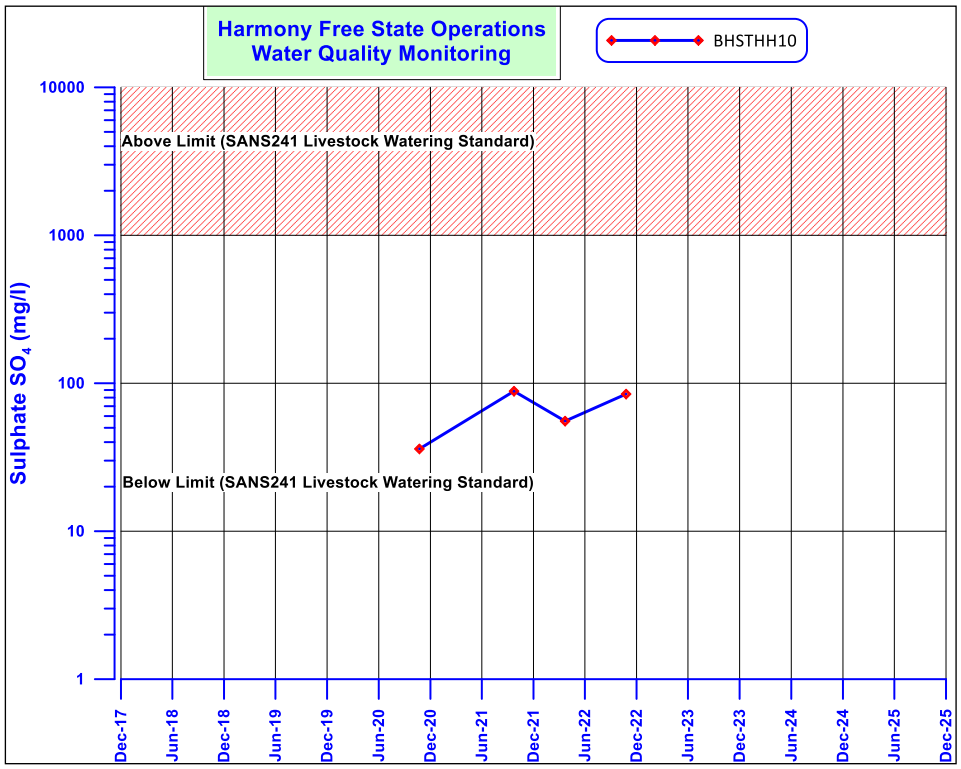

Harmony Free State Operations
Water Quality Monitoring
BHP9
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

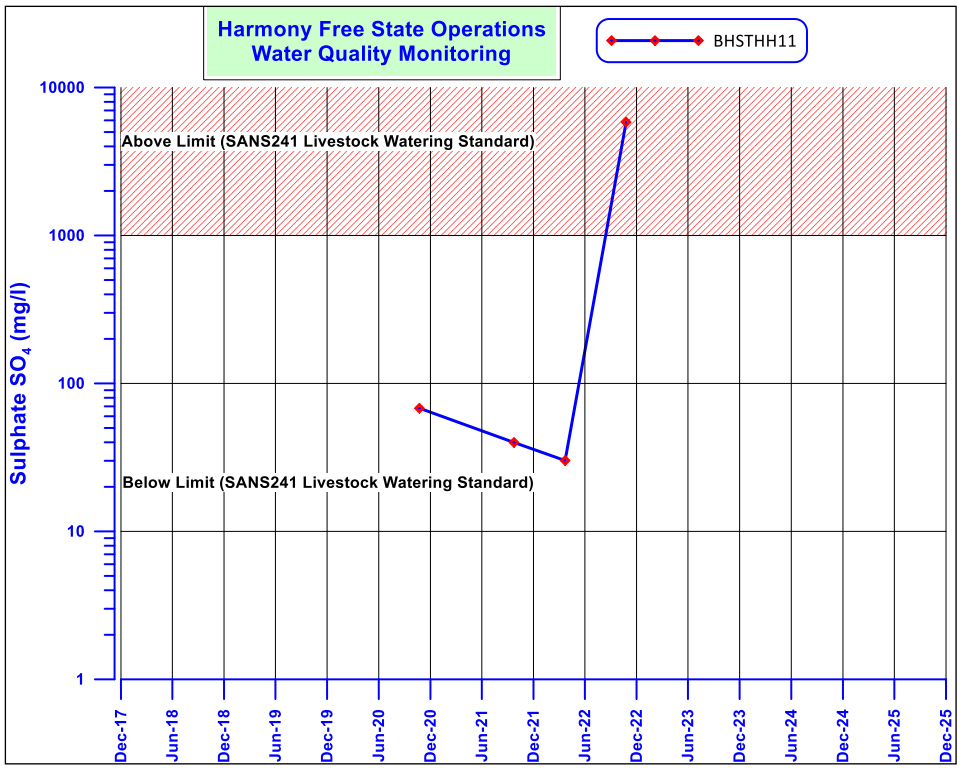

Harmony Free State Operations
Water Quality Monitoring
BHRiver
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

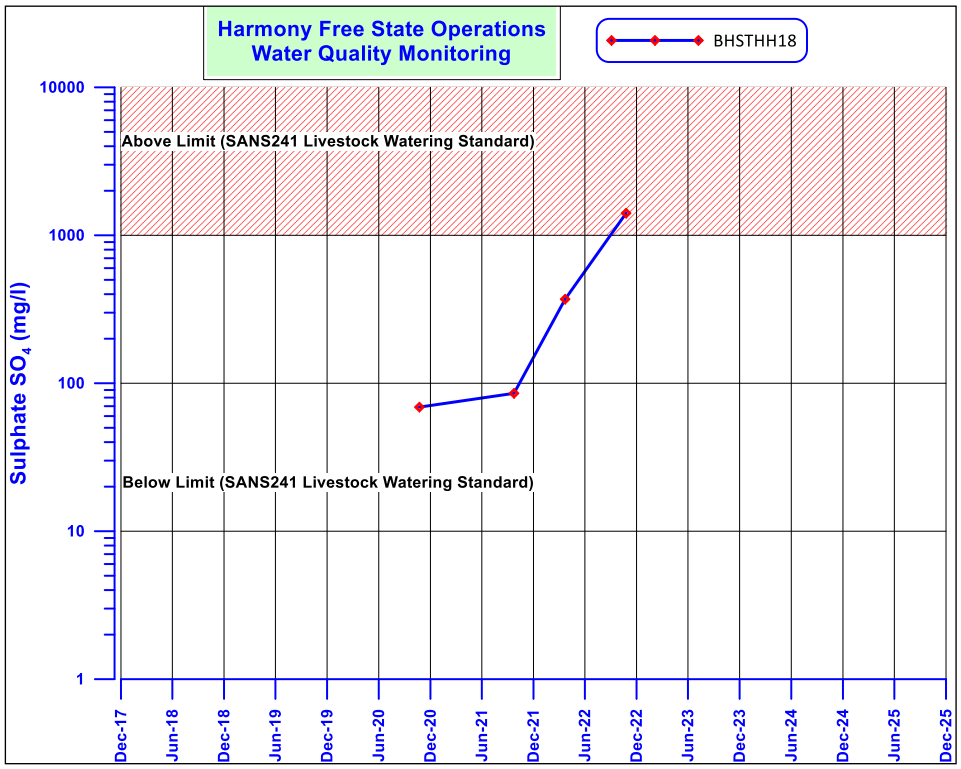

Harmony Free State Operations
Water Quality Monitoring
BHSTHH02
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

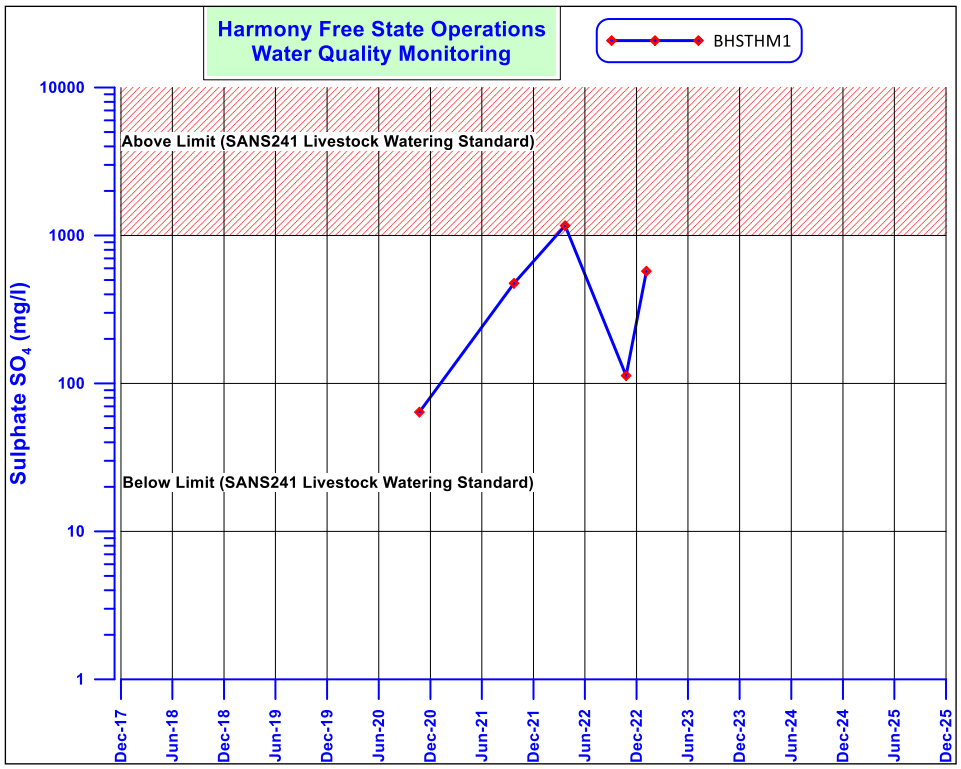

Harmony Free State Operations
Water Quality Monitoring
BHSTHH04
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

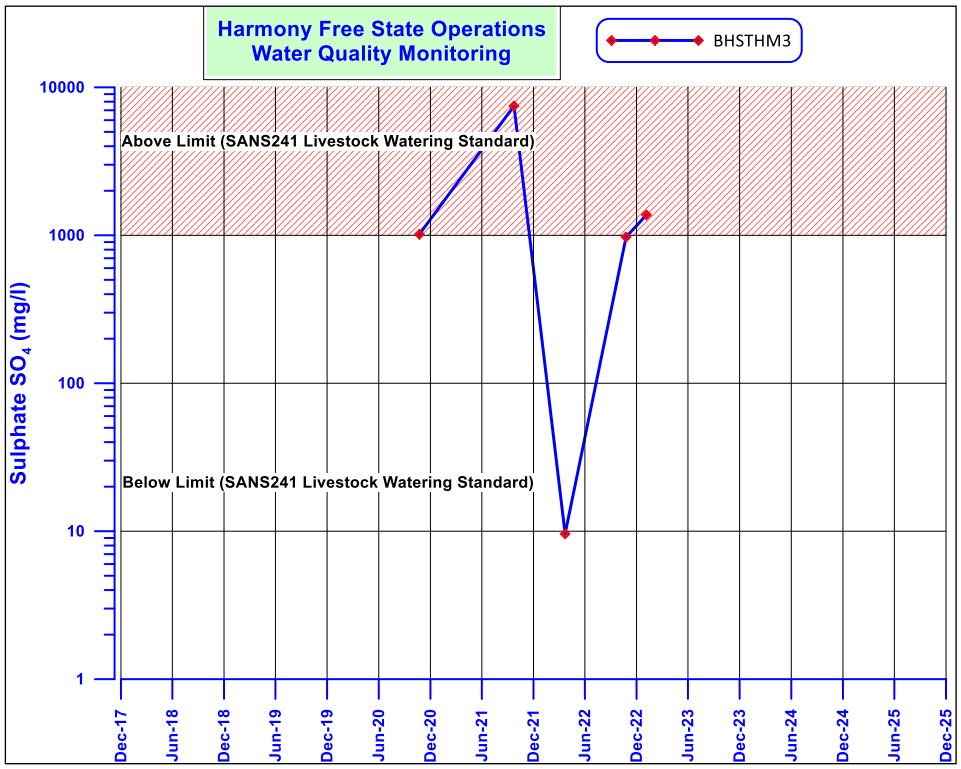

Harmony Free State Operations
Water Quality Monitoring
BHSTHH08
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

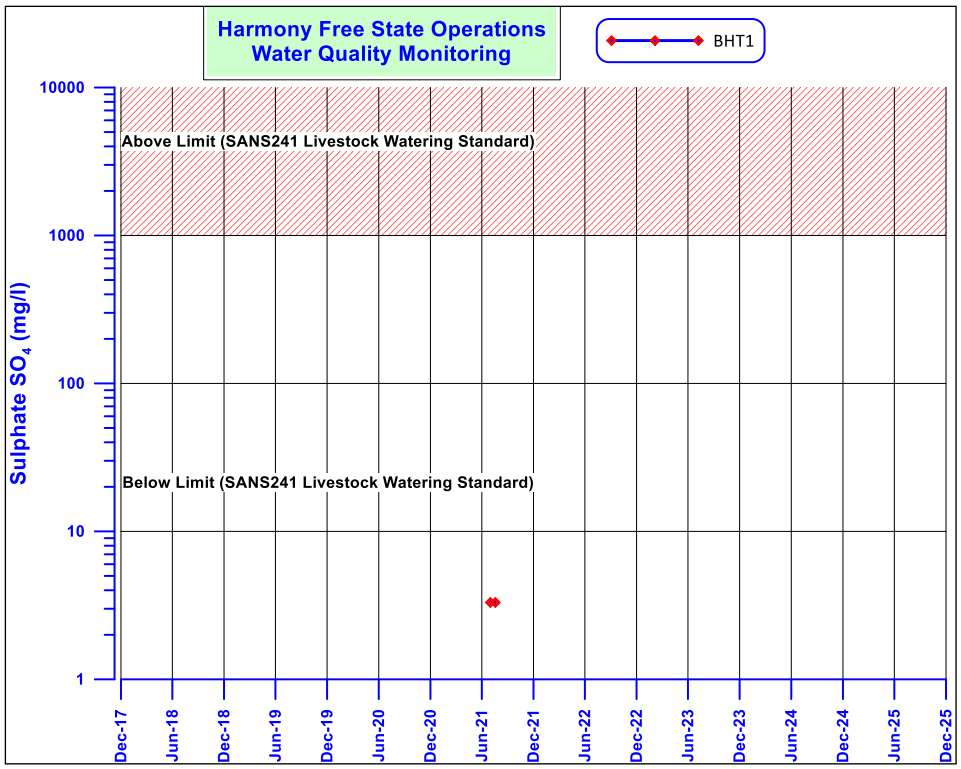

Harmony Free State Operations
Water Quality Monitoring
BHSTHH10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

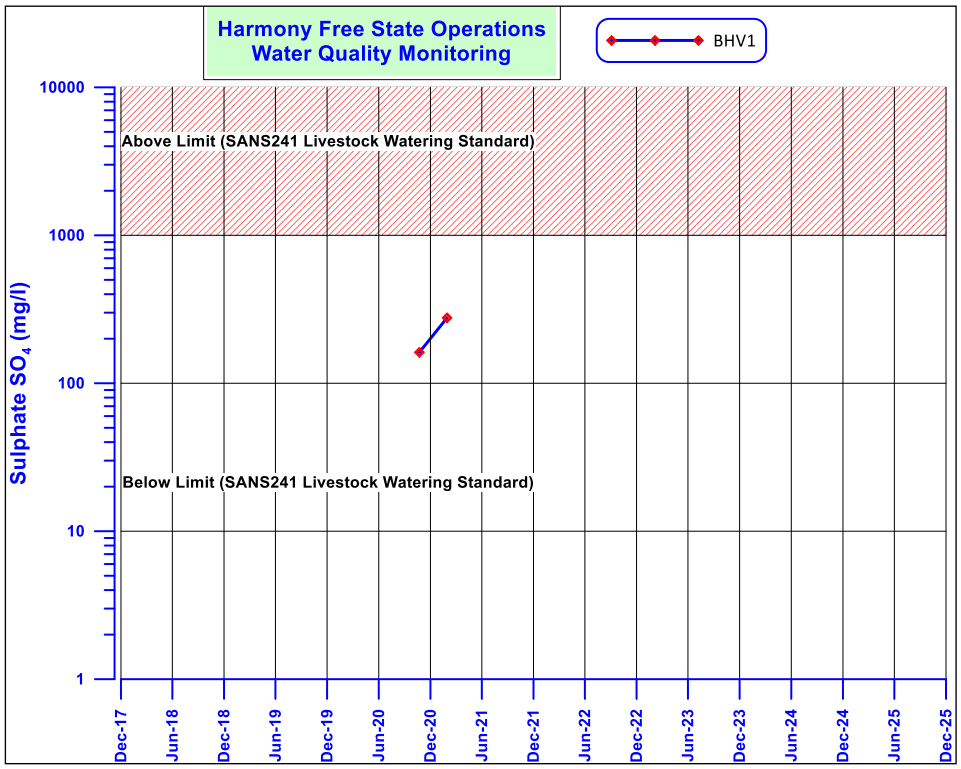

Harmony Free State Operations
Water Quality Monitoring
BHSTHH11
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

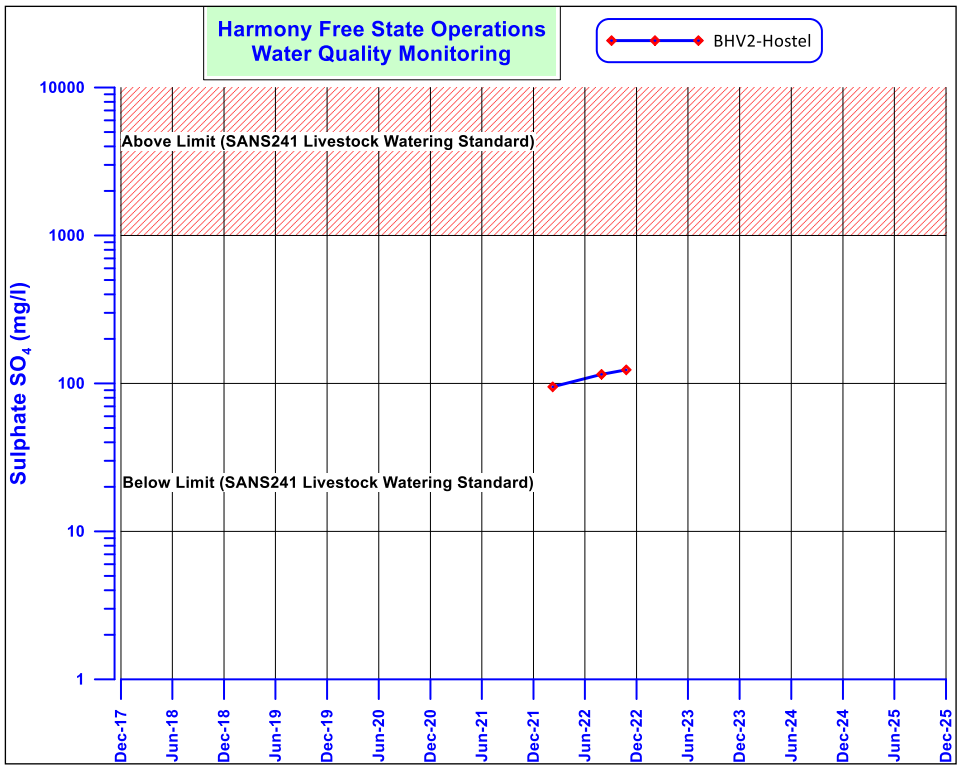

Harmony Free State Operations
Water Quality Monitoring
BHSTHH18
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

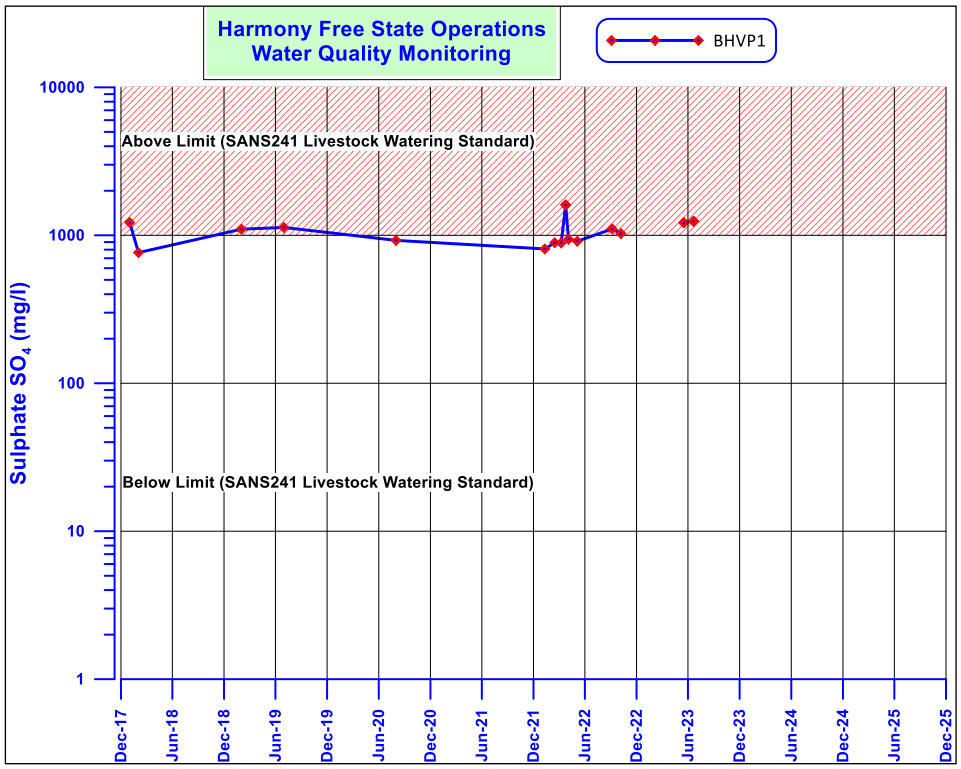

Harmony Free State Operations
Water Quality Monitoring
BHSTHM1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

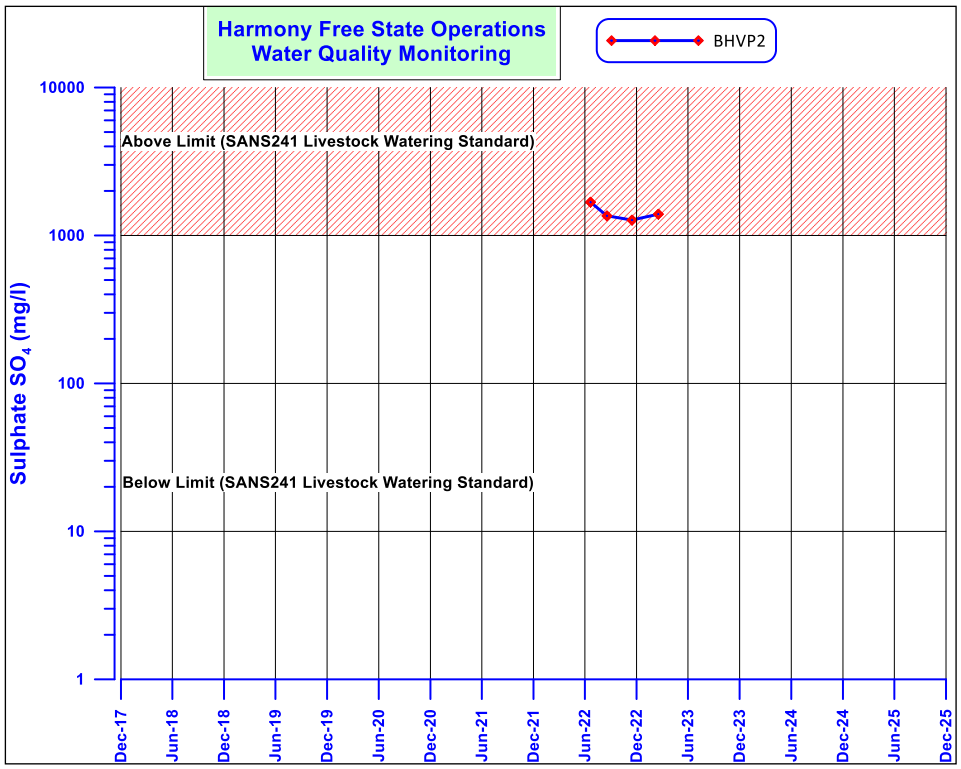

Harmony Free State Operations
Water Quality Monitoring
BHSTHM3
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

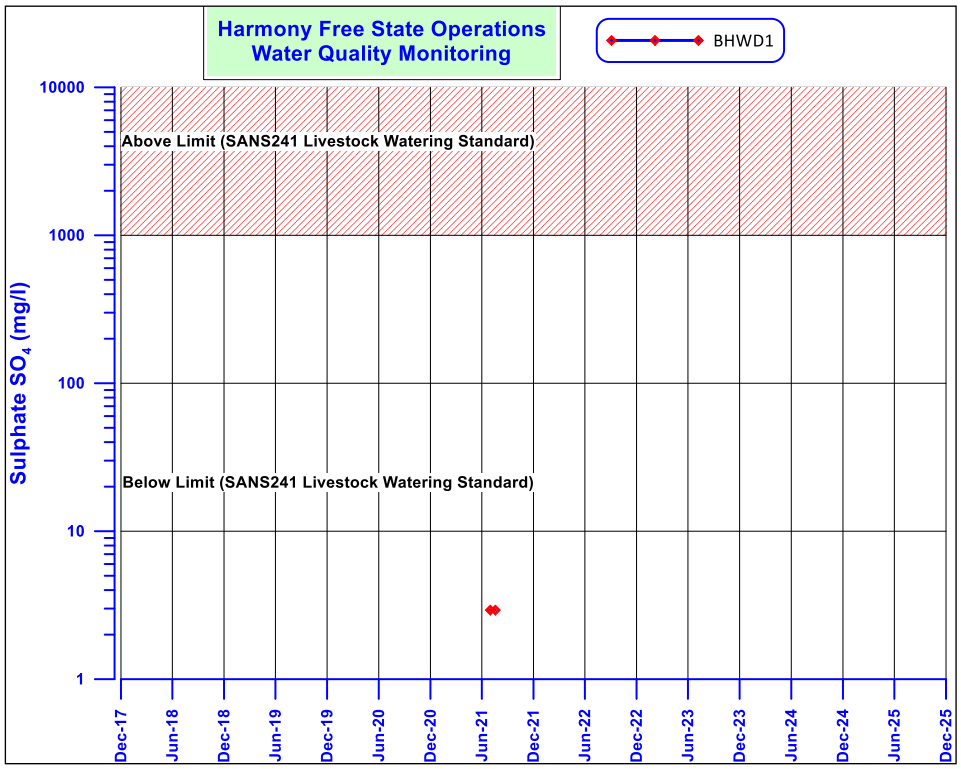

Harmony Free State Operations
Water Quality Monitoring
BHT1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

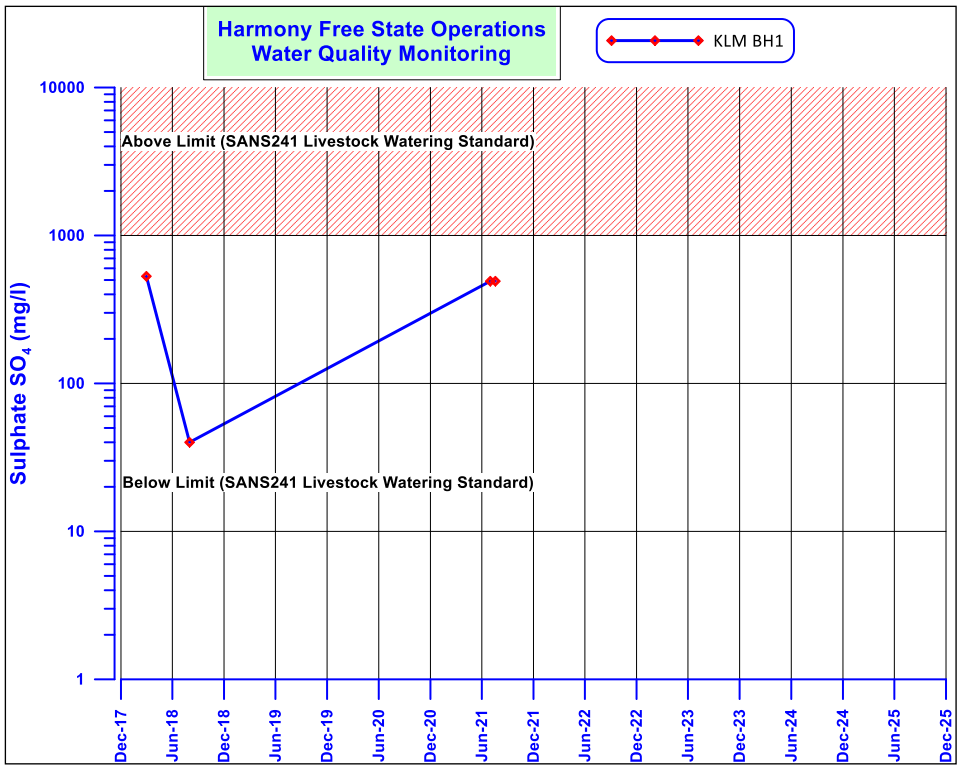

Harmony Free State Operations
Water Quality Monitoring
BHV1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

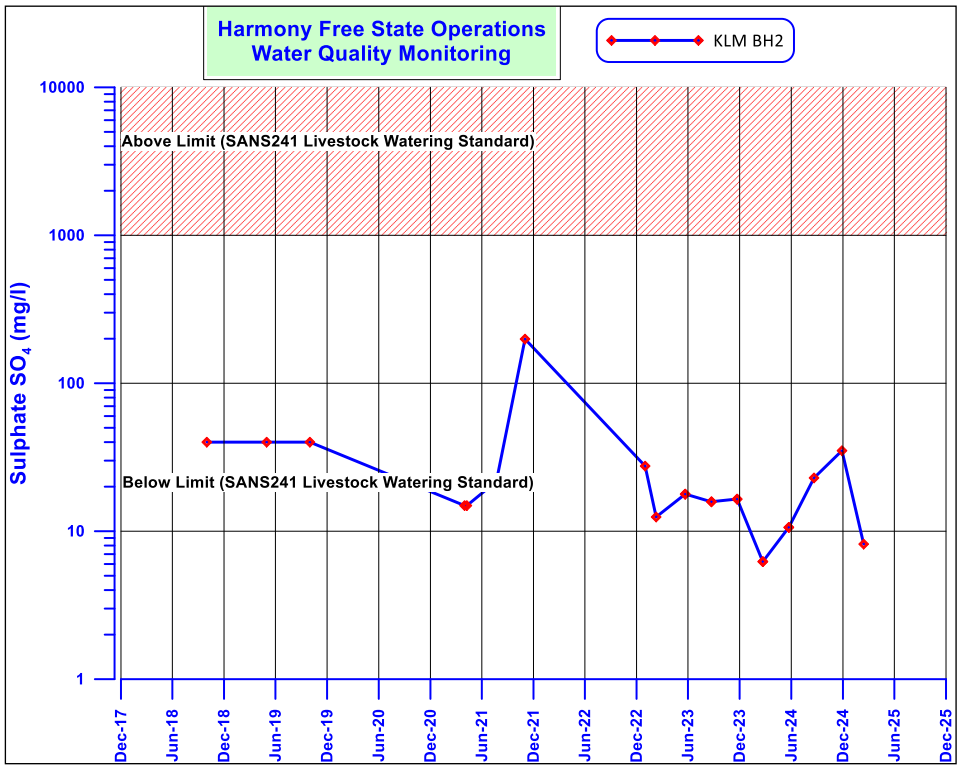

Harmony Free State Operations
Water Quality Monitoring
BHV2-Hostel
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

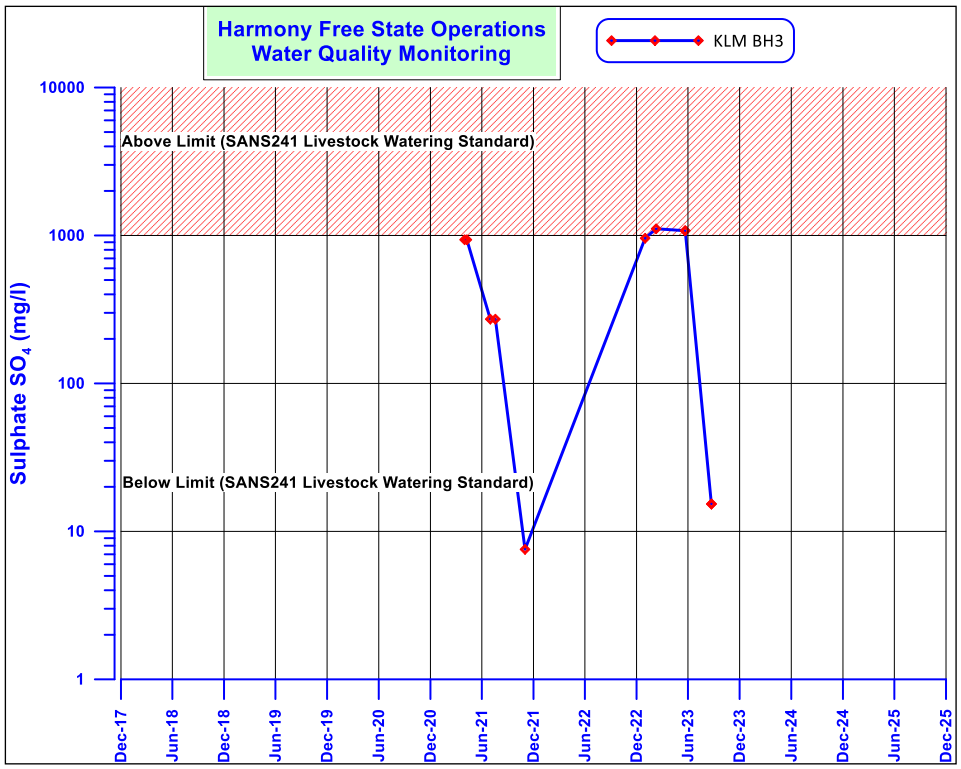

Harmony Free State Operations
Water Quality Monitoring
BHVP1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

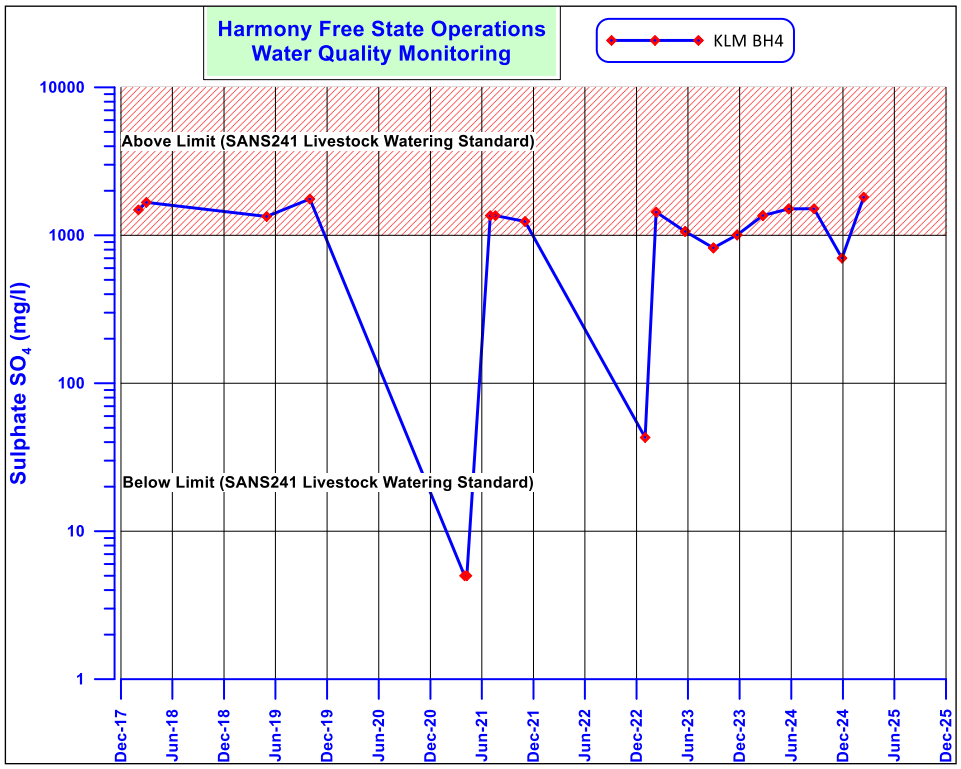

Harmony Free State Operations
Water Quality Monitoring
BHVP2
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

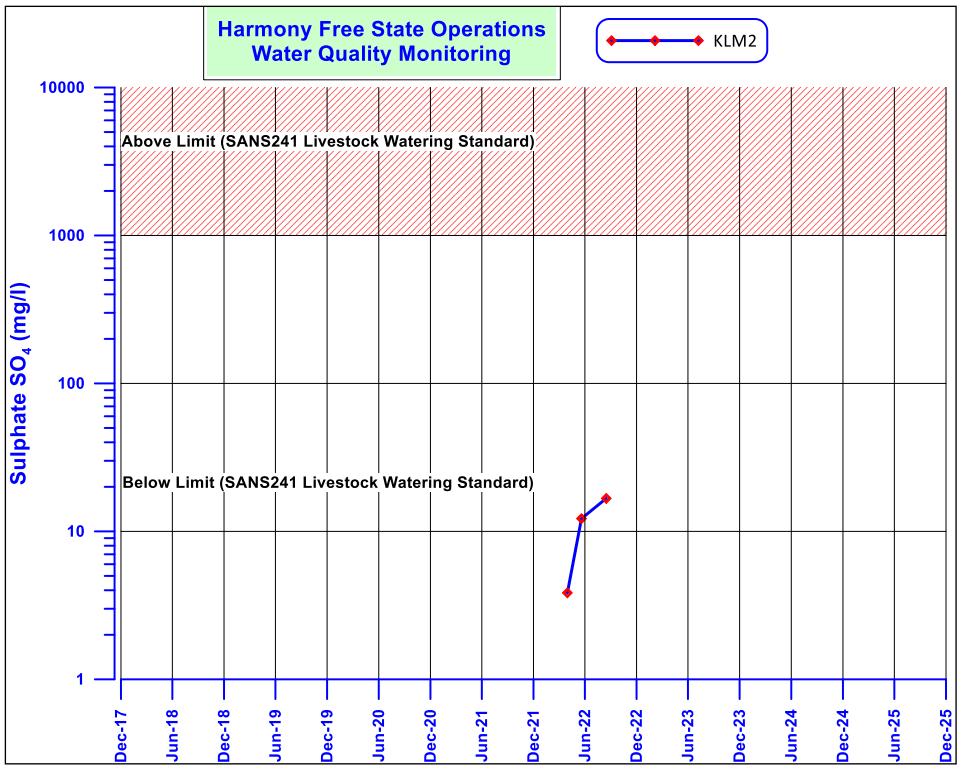

Harmony Free State Operations
Water Quality Monitoring
BHWD1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

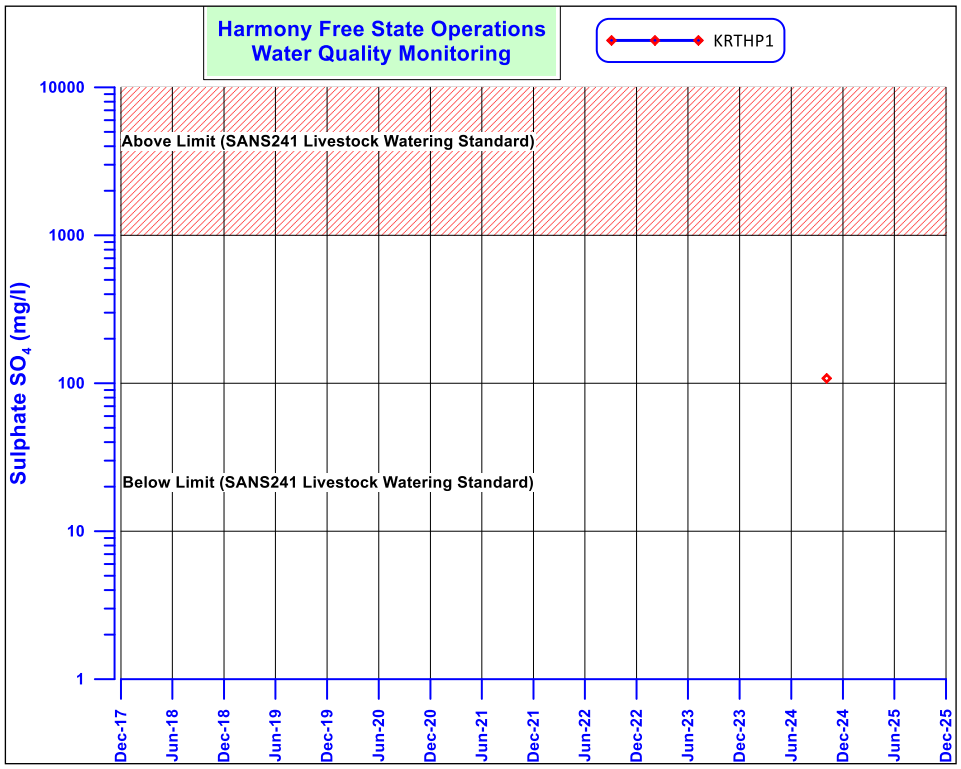

Harmony Free State Operations
Water Quality Monitoring
KLM BH1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

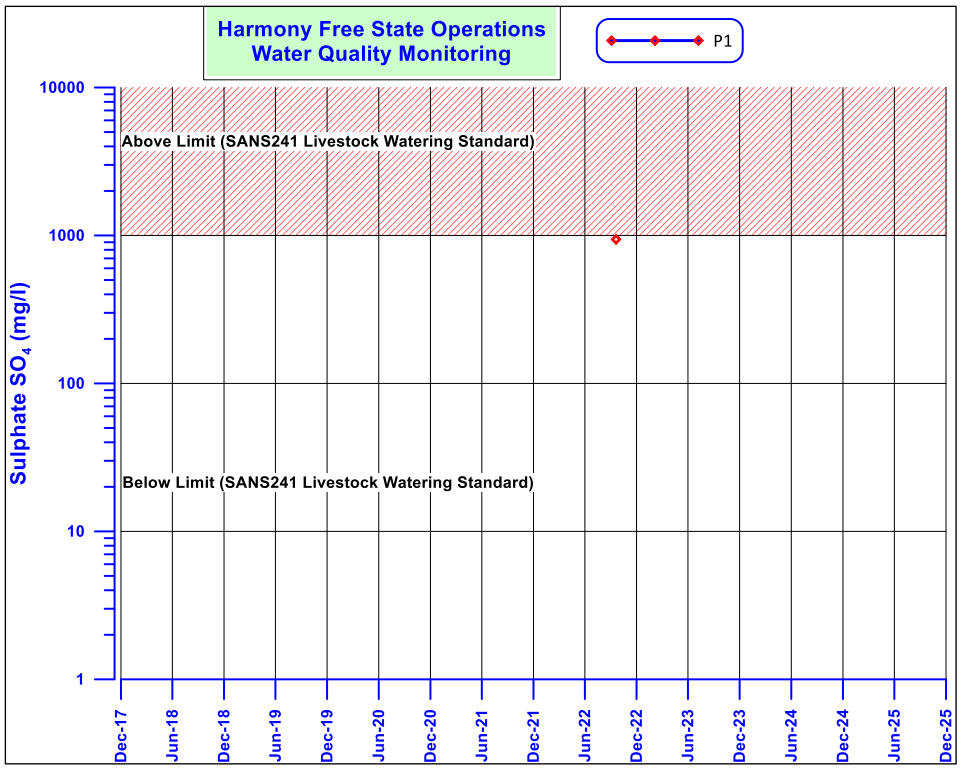

Harmony Free State Operations
Water Quality Monitoring
KLM BH2
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

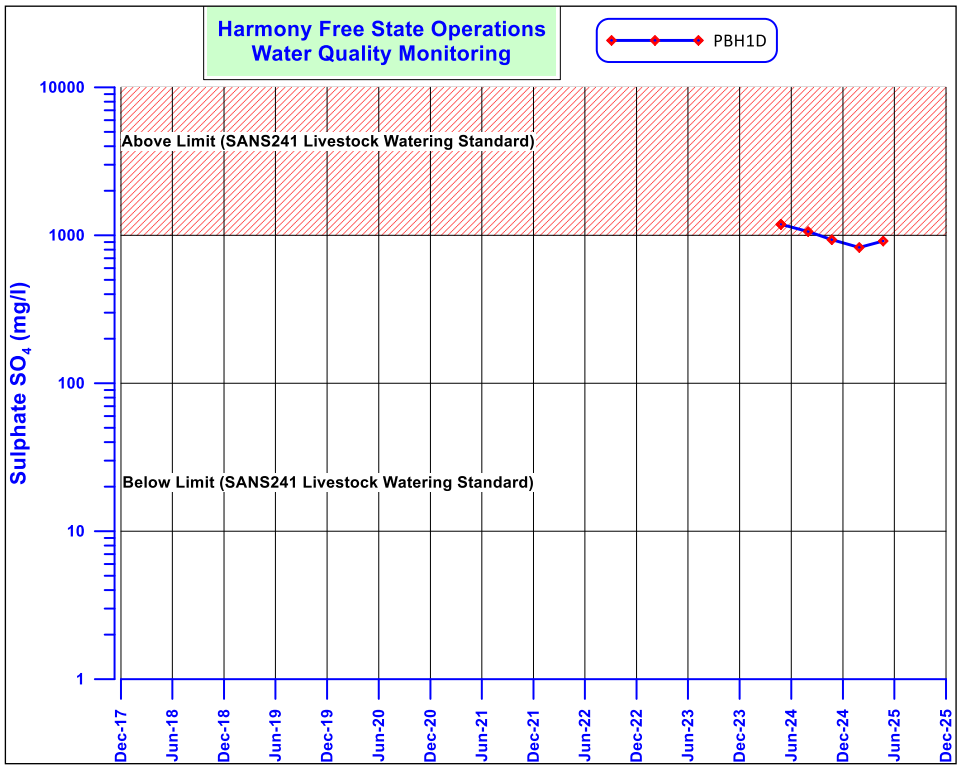

Harmony Free State Operations
Water Quality Monitoring
KLM BH3
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

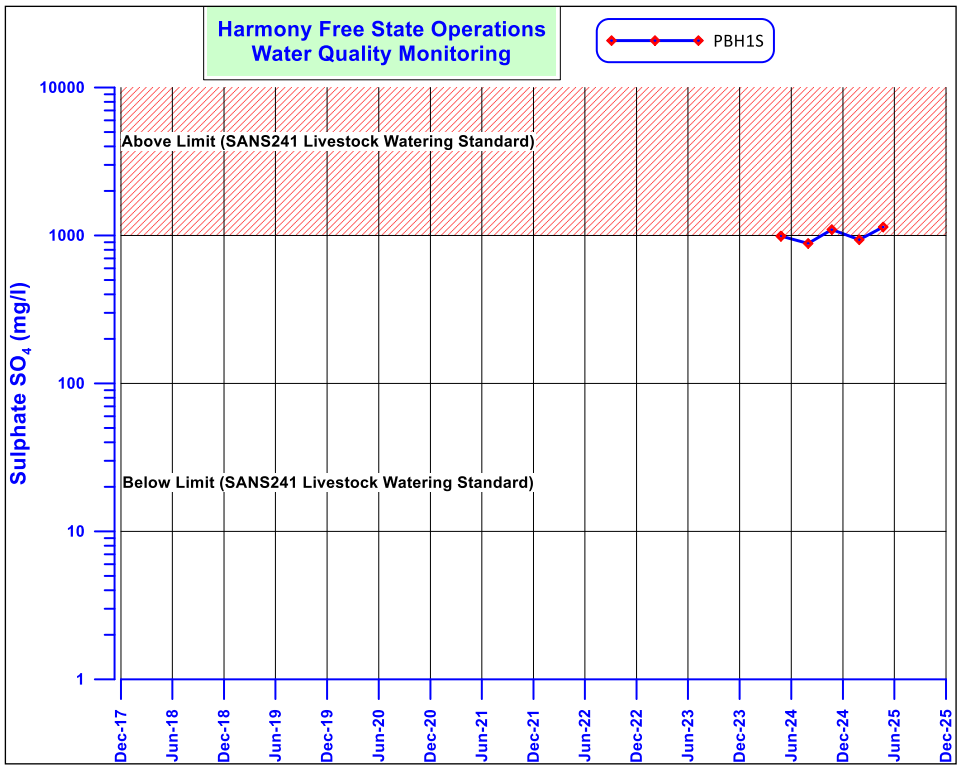

Harmony Free State Operations
Water Quality Monitoring
KLM BH4
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

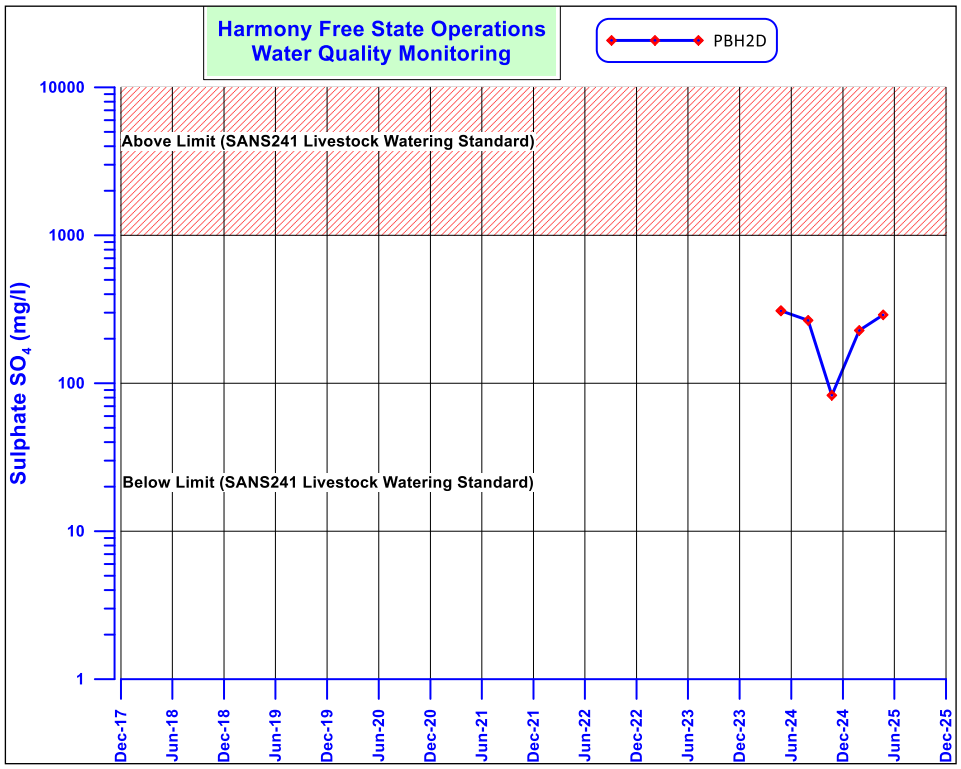

Harmony Free State Operations
Water Quality Monitoring
KLM2
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

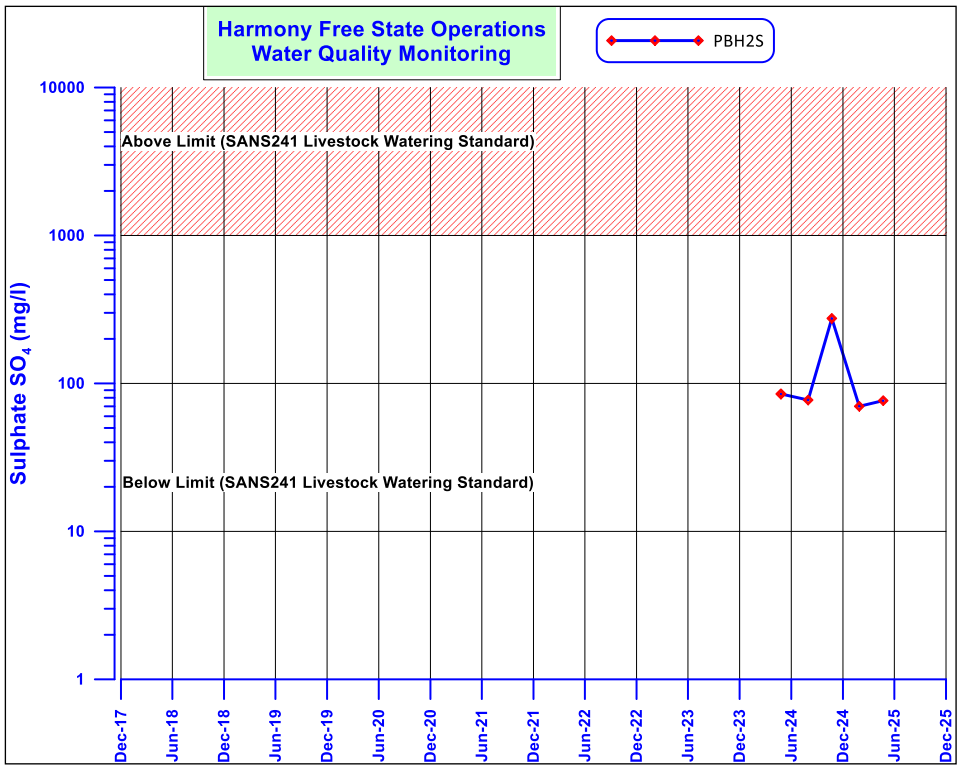

Harmony Free State Operations
Water Quality Monitoring
KRTHP1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

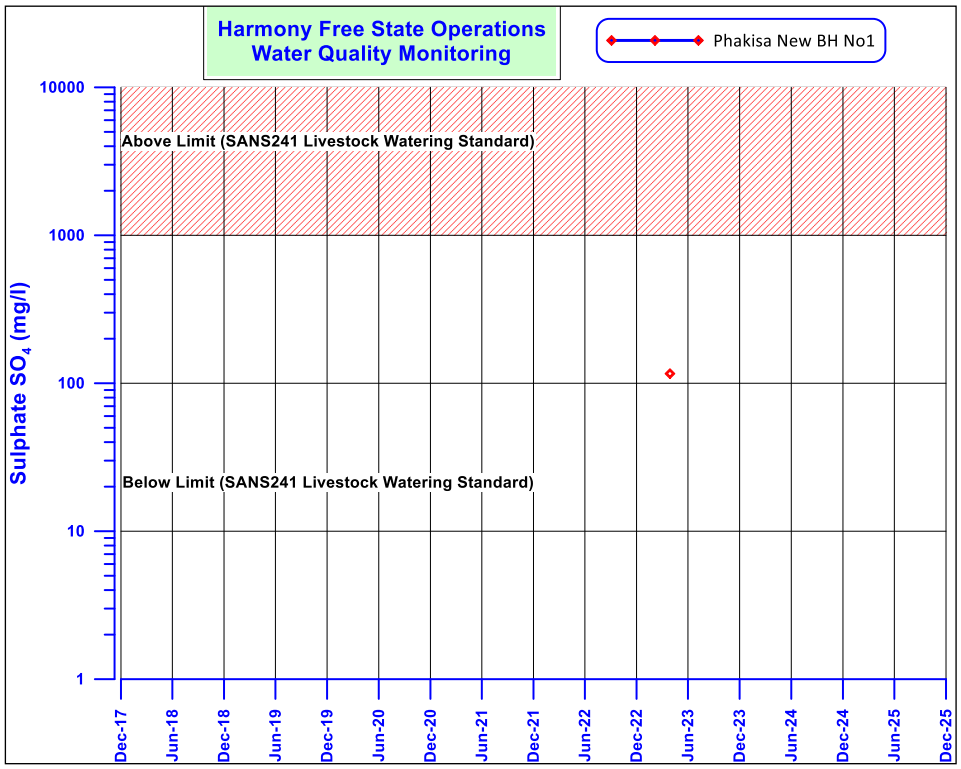

Harmony Free State Operations
Water Quality Monitoring
P1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

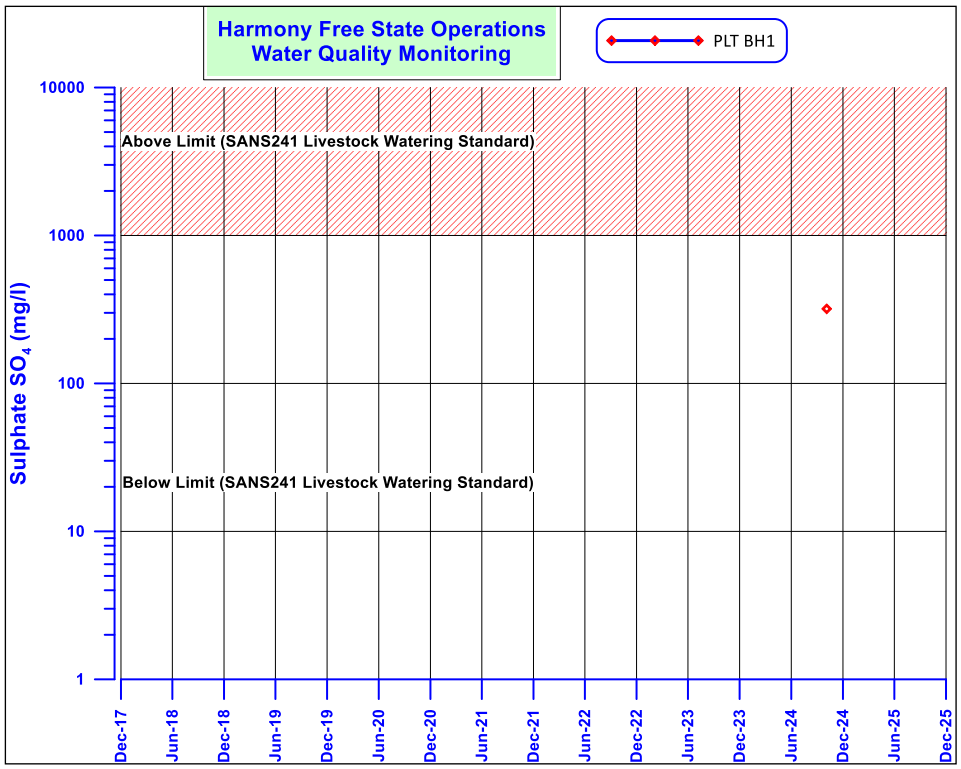

Harmony Free State Operations
Water Quality Monitoring
PBH1D
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

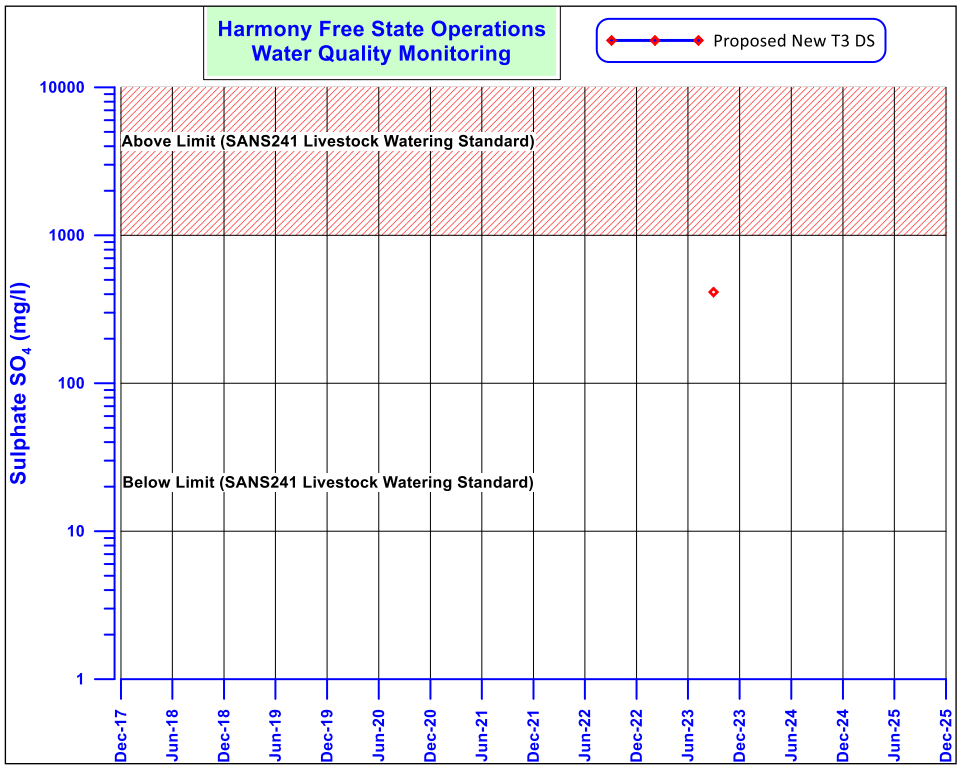

Harmony Free State Operations
Water Quality Monitoring
PBH1S
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

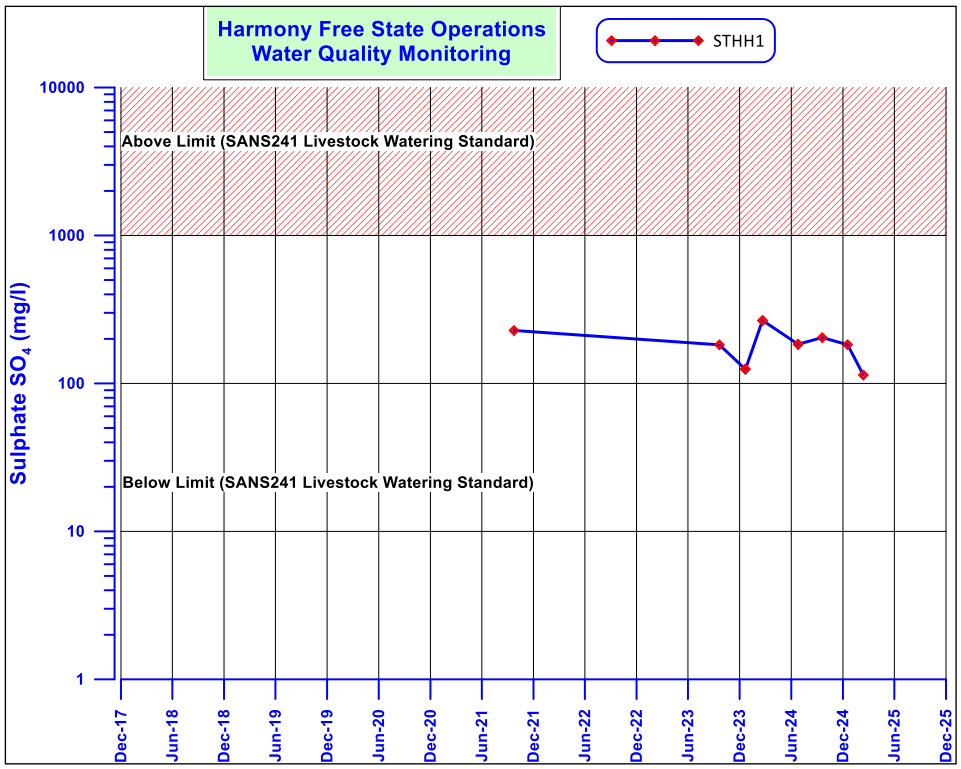

Harmony Free State Operations
Water Quality Monitoring
PBH2D
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

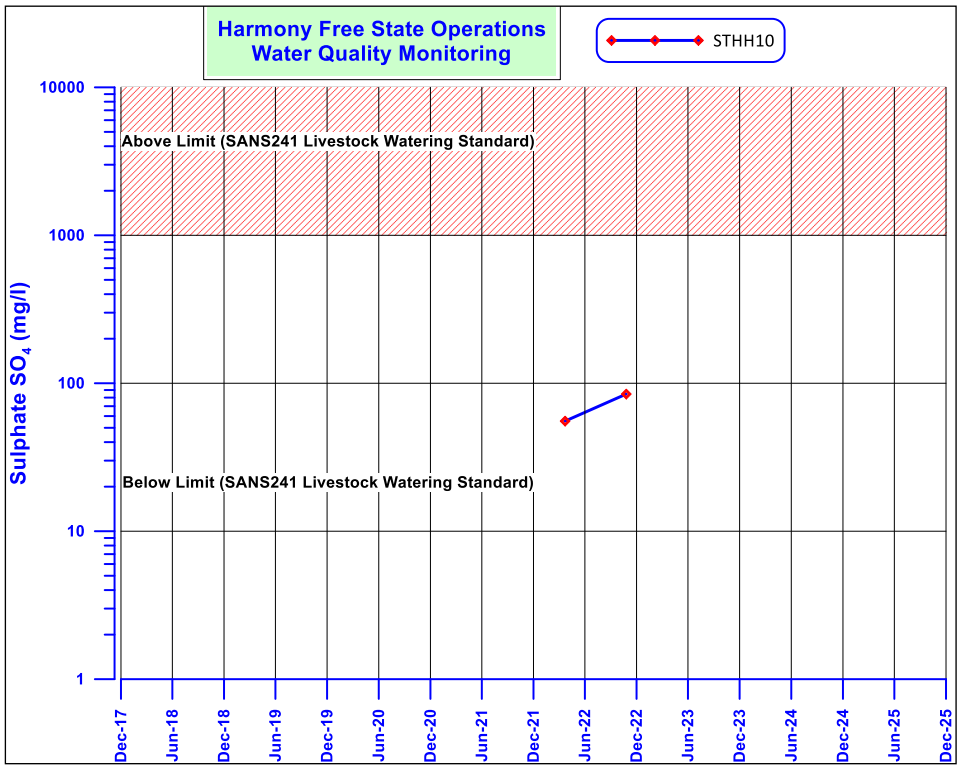

Harmony Free State Operations
Water Quality Monitoring
PBH2S
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

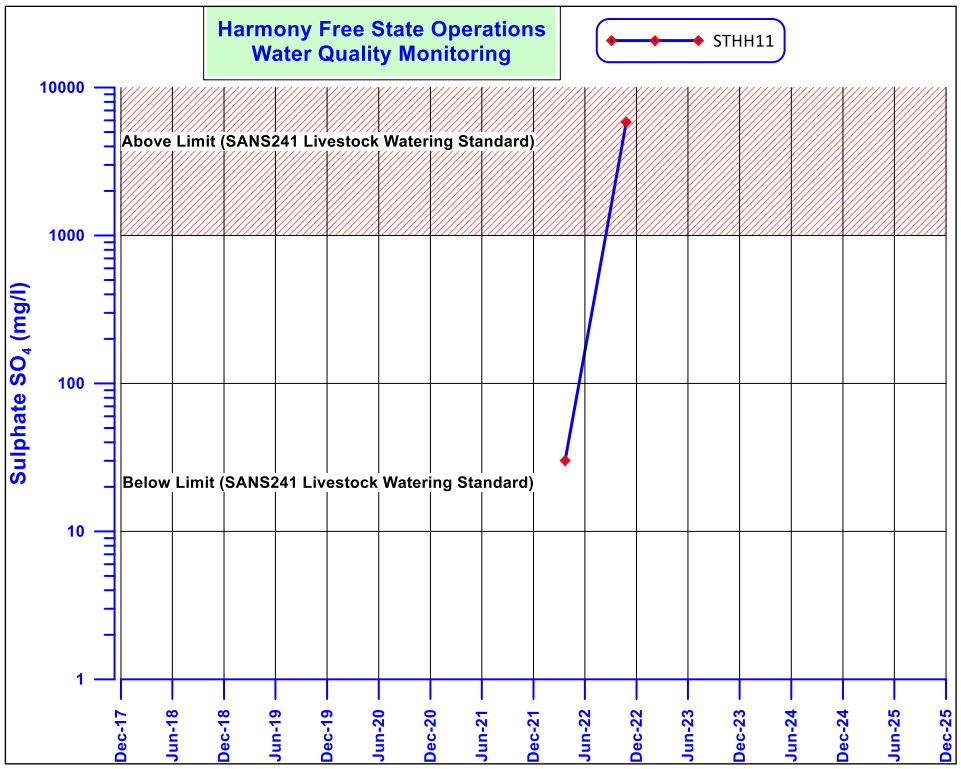

Harmony Free State Operations
Water Quality Monitoring
Phakisa New BH No1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

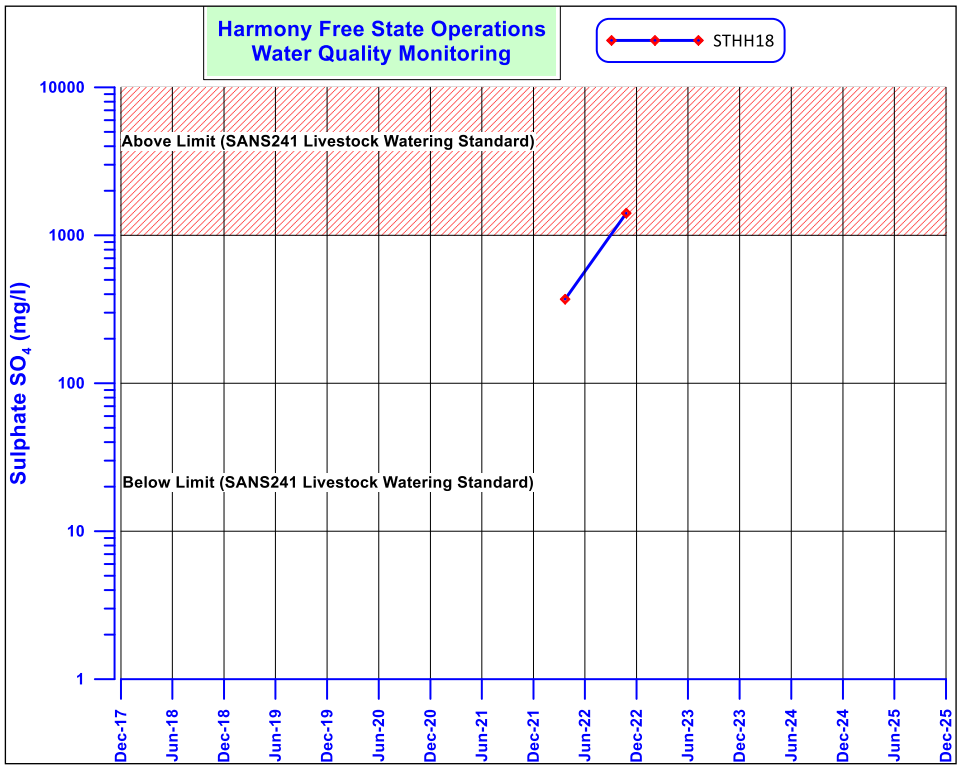

Harmony Free State Operations
Water Quality Monitoring
PLT BH1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

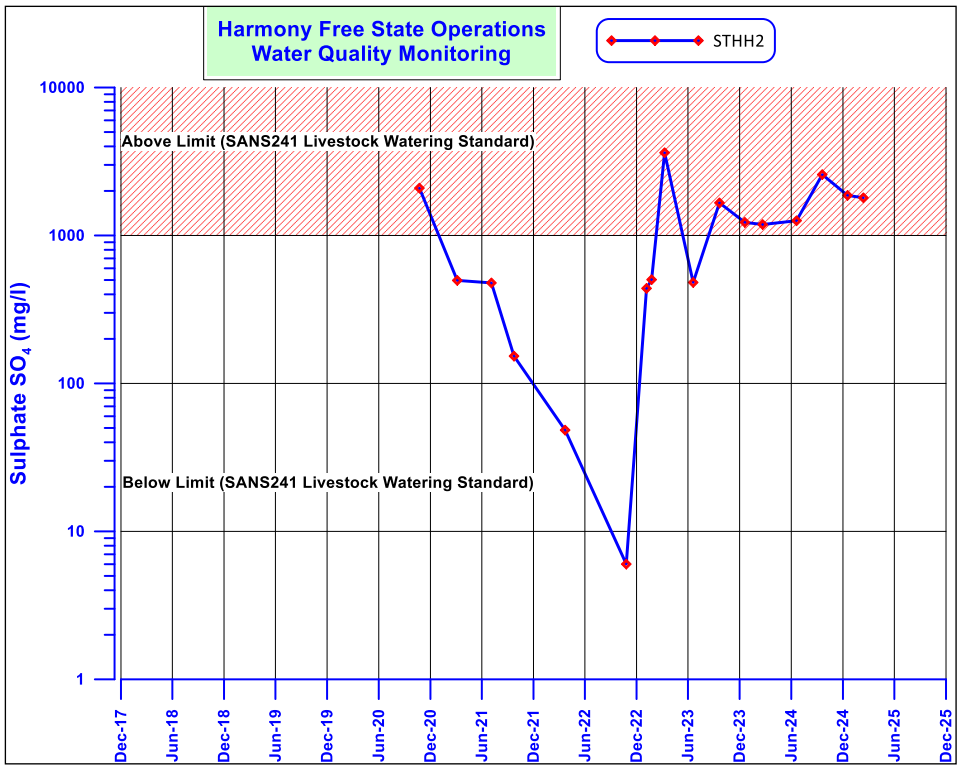

Harmony Free State Operations
Water Quality Monitoring
Proposed New T3 DS
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

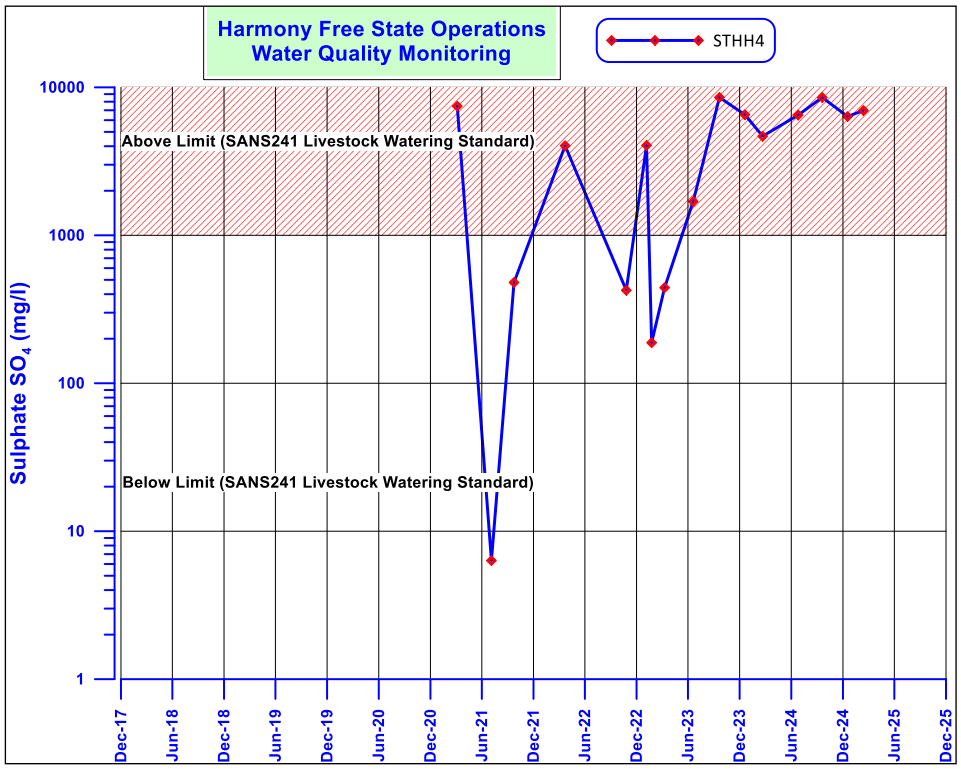

Harmony Free State Operations
Water Quality Monitoring
STHH1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

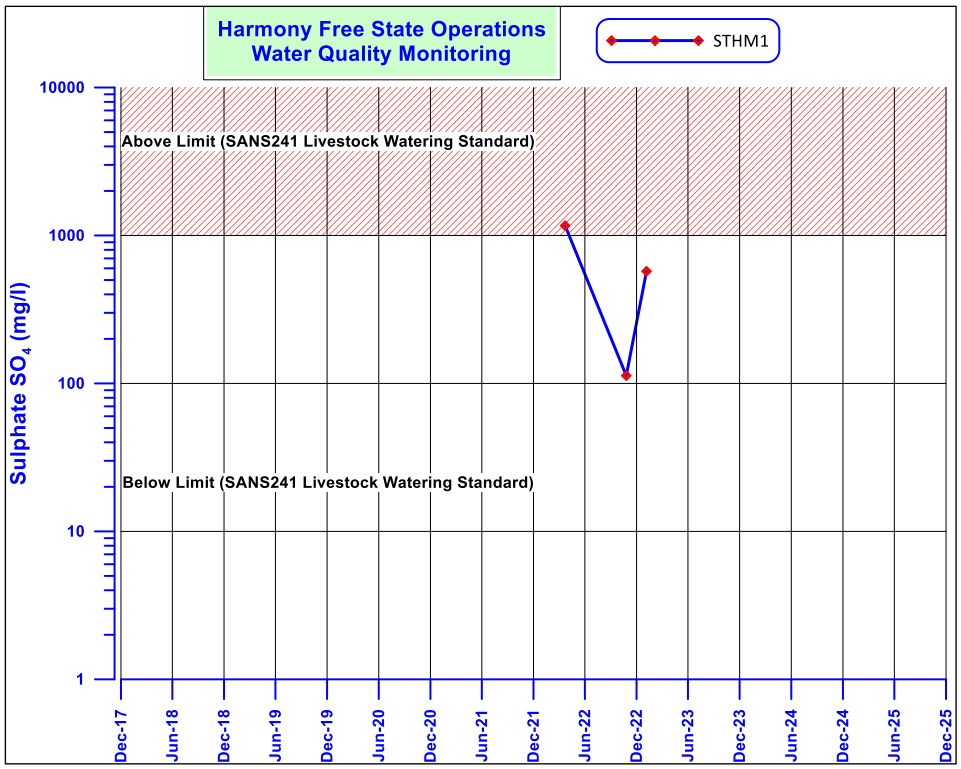

Harmony Free State Operations
Water Quality Monitoring
STHH10
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

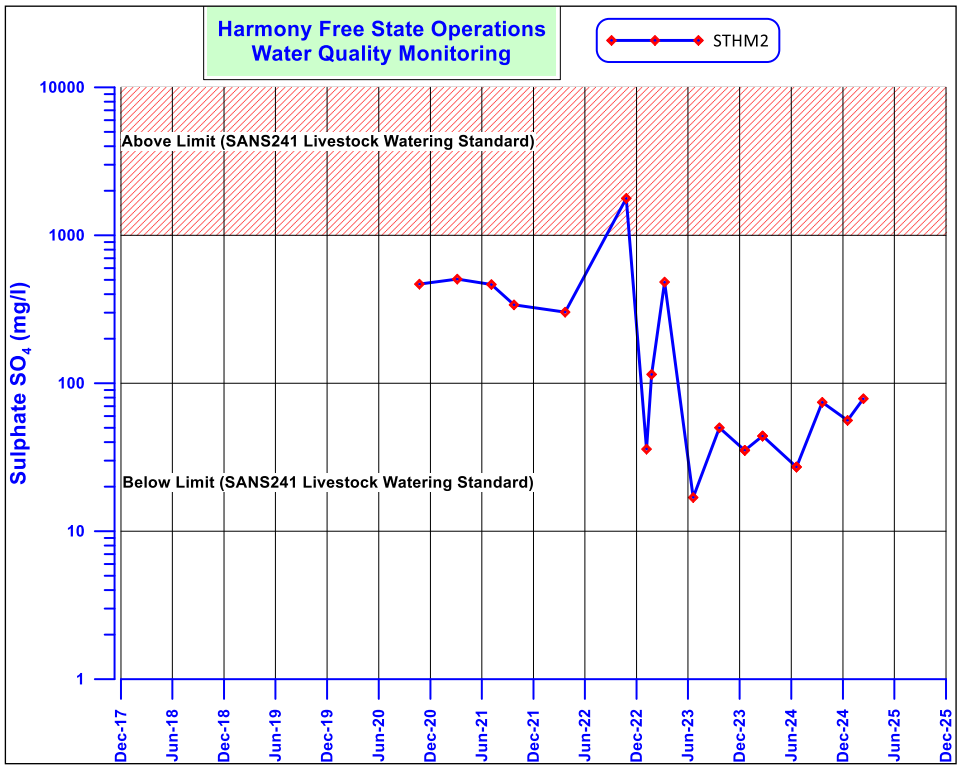

Harmony Free State Operations
Water Quality Monitoring
STHH11
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25

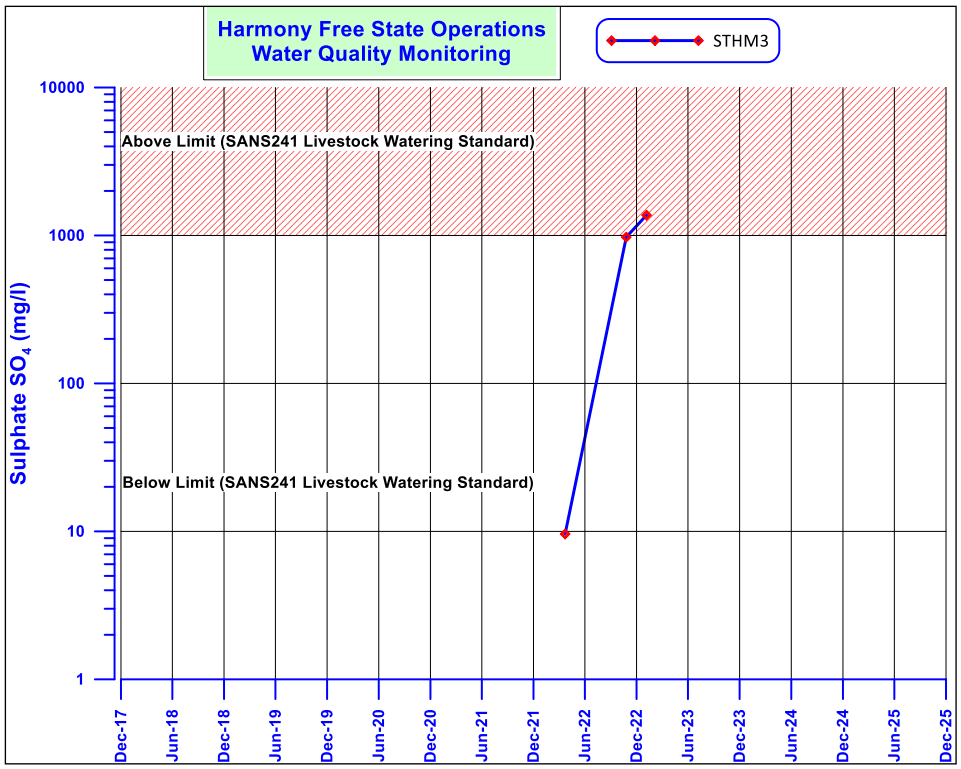

Harmony Free State Operations
Water Quality Monitoring
STHH18
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25


Harmony Free State Operations
Water Quality Monitoring
STHH2
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25


Harmony Free State Operations
Water Quality Monitoring
STHH4
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25


Harmony Free State Operations
Water Quality Monitoring
STHM1
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25


Harmony Free State Operations
Water Quality Monitoring
STHM2
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25


Harmony Free State Operations
Water Quality Monitoring
STHM3
Above Limit (SANS241 Livestock Watering Standard)
Below Limit (SANS241 Livestock Watering Standard)
Sulphate SO4 (mg/l)
10000
1000
100
10
1
Dec-17
Jun-18
Dec-18
Jun-19
Dec-19
Jun-20
Dec-20
Jun-21
Dec-21
Jun-22
Dec-22
Jun-23
Dec-23
Jun-24
Dec-24
Jun-25
Dec-25