TRANSALLOYS (PTY) LTD

GEOHYDROLOGICAL ASSESSMENT OF THE FERROCHROME SLIMES DAM AT TRANSALLOYS (PTY) LTD

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1. INTRODUCTION

1.1 Project Background

The Transalloys (Pty) Ltd (Transalloys) Smelter Plant is situated approximately 14 kilometres west of eMalahleni (**Figure 1.1**). The plant is situated on the Remainder of Portions 20 and 24 of the farm Schoongezicht 308 JS and the Remaining Extent of Portion 34 of the farm Elandsfontein 309 JS, eMalahleni Local Municipality, within Nkangala District Municipality: Mpumalanga Province.

Transalloys is the producer of silico-manganese (Si-Mn) and medium (MCFeMn) and high ferromanganese (HCFeMn) product in South Africa and a recognised supplier of the product globally, with a capacity to produce 165 000 tons of Si-Mn per annum, produced through five submerged arc furnaces.

Waste material and discard from the process is disposed at several waste facilities on site. Transalloys proposes to close the redundant Ferrochrome Slimes Dam (FSD). The FSD is a lined facility that will be closed and rehabilitated. The detailed rehabilitation plan is still being developed but it is understood that it will be fully encapsulated. From a geohydrological perspective the encapsulation of a waste body effectively removes the facility as a contaminant source as contaminated seepage into the groundwater will no longer take place.

1.2 Scope and Purpose of the Study

The aim of this report is to assess the current and future geohydrological impacts from the FSD on the groundwater regime.

This report provides a summary on the geohydrological conditions at Transalloys, based on previous investigations. A numerical groundwater flow and mass transport model was previously constructed, and this model was utilised in the assessment.

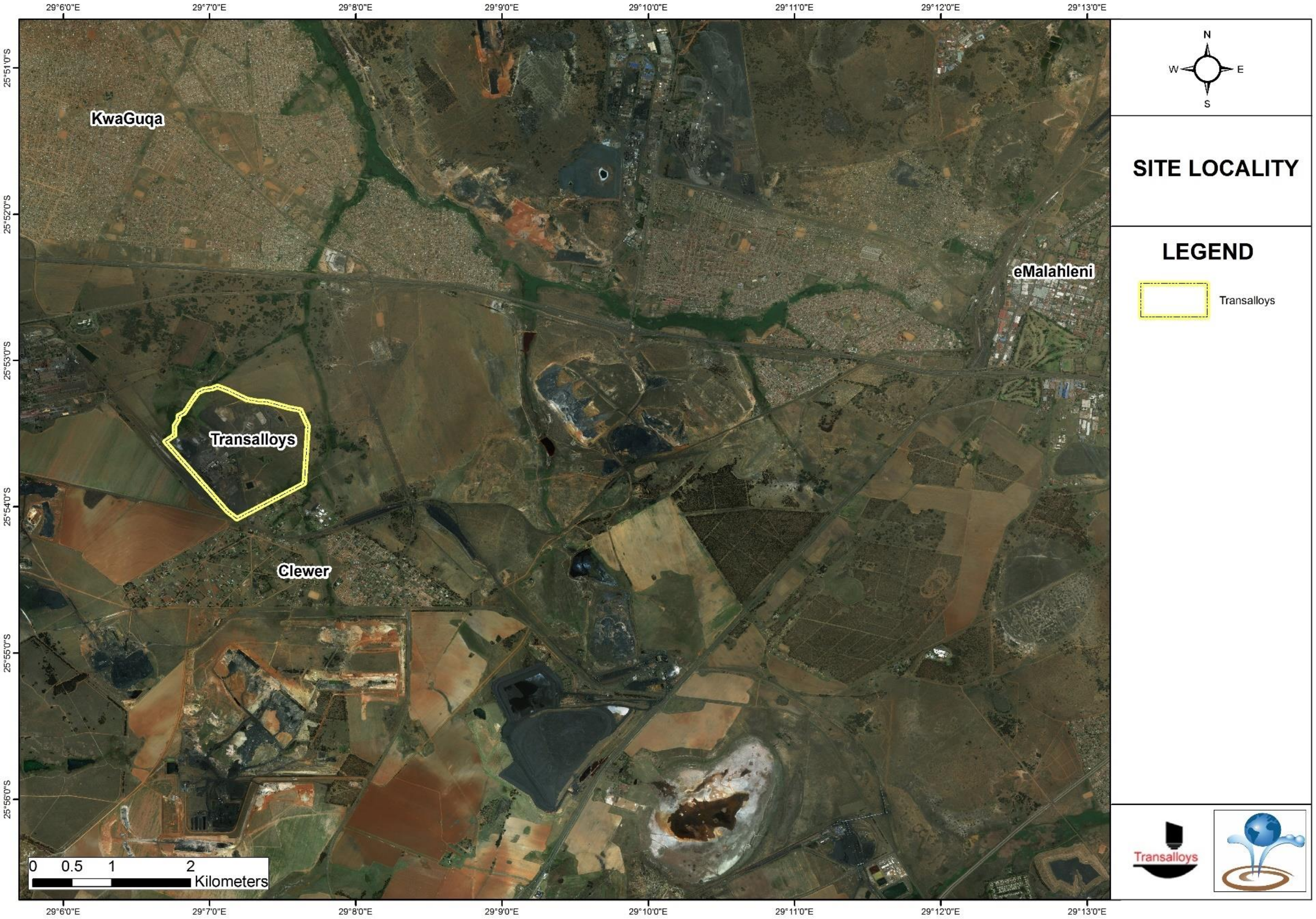


Figure 1.1: Locality map

1.3 Report Structure

This geohydrological investigation was undertaken according to the Department of Water Affairs Best Practice Guideline G4 (Impact Prediction) (DWA BPG G4, 2008). Based on this guideline the broad outline of the report is as follows:

- Site and source description.
  - Existing waste facilities.
  - Contaminant source description.
- Groundwater Pathway.
  - Site geology.
  - Conceptual geohydrological model.
  - Hydrochemistry.
- Description of the receptors.
- Numerical groundwater modelling.
  - Groundwater flow model.
  - Contaminant transport model.
- Geohydrological impact assessment.

2. GEOHYDROLOGICAL CONCEPTUAL MODEL

2.1 Introduction

The methodology prescribed in the BPG (DWAF, 2008) for development of the Impact Prediction, follows a risk-based approach, which is aimed at defining and understanding the three components of the risk, namely:

- The source.
- The pathway along which the risk propagates.
- The receptor that experiences the risk.

The sources are characterised based on the studies as conducted by INFOTOX (Van Niekerk, 2018). Results from the source characterisation were utilised to evaluate the transfer of contaminants from the waste disposal sites, via the groundwater pathway, to receptors. The evaluation of the groundwater pathway was performed as part of a numeric geohydrological flow and contaminant transport model developed specifically for Transalloys property.

The purpose of this section is to present the complete conceptual understanding of the potential for impact from the Transalloys operations, activities and processes, in terms of the three components of the Source-Pathway-Receptor analysis, using the findings of the updated geohydrological model.

2.2 Description of the Sources

2.2.1 Current Waste Management Facilities

The source quality was analysed to gain insights into both the total and leachable concentrations. This assessment was based on recent studies conducted by INFOTOX (Van Niekerk, 2018) as well as previous studies by Pulles, Howard and De Lange (PHD, 2008) and TerraSoils (2016). The findings of these assessments were used to assign concentrations to the various sources in the numerical groundwater model. The existing contaminant sources at Transalloys include the following sites (**Figure 2.1**):

- Mn slag dump.
- Mn slimes dam.
- Fe-Cr slimes dam.
- Historical raw material stockpile.
- Sewage evaporation ponds.
- Waste storage area.
- Raw material storage area.

The localities of the existing contaminant sources are shown on **Figure 2.1**.

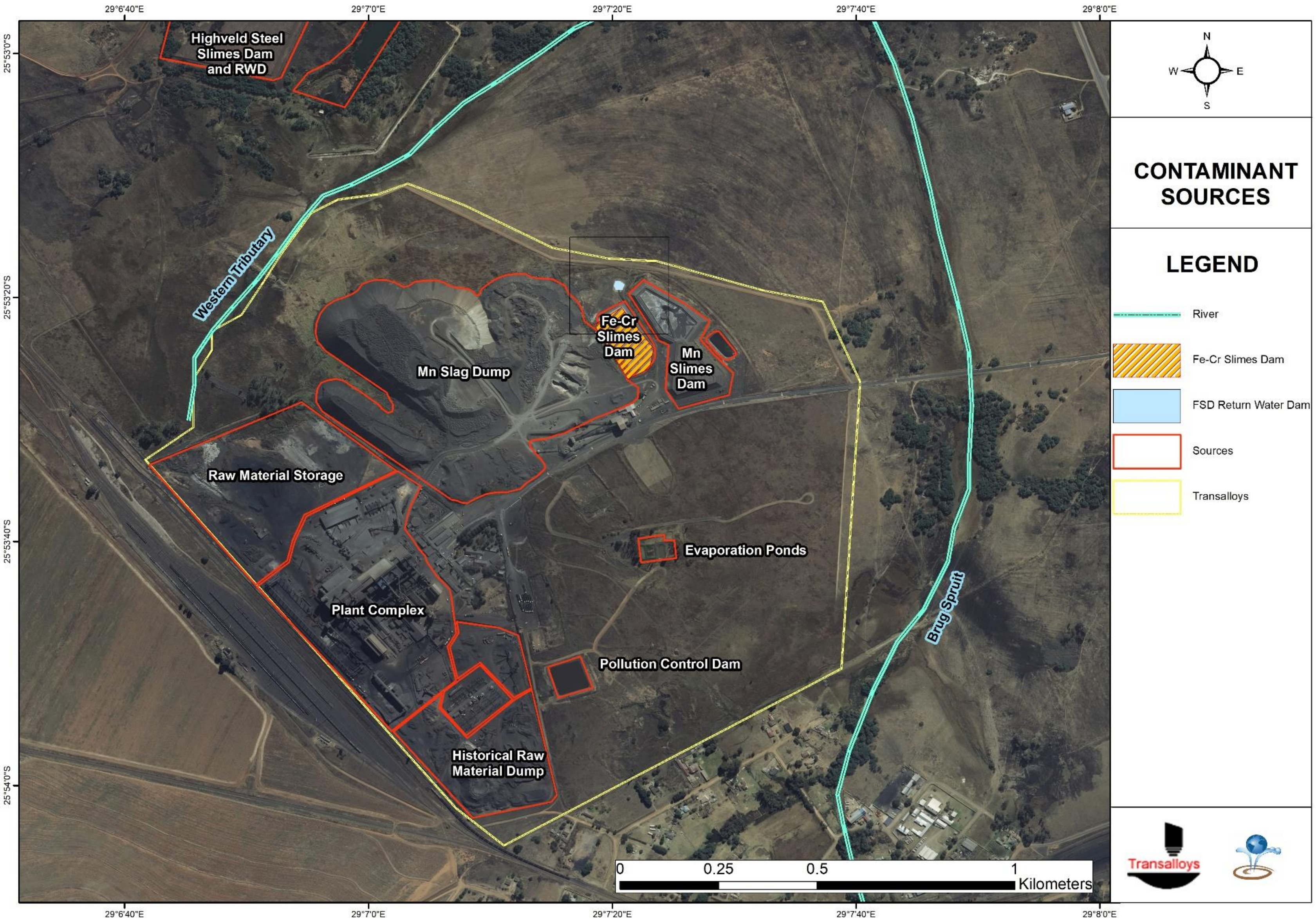


Figure 2.1: **Existing sources at Transalloys**

2.2.2 Contaminant Source Description

The primary contaminant sources at Transalloys, ranked according to estimated risk, is listed below:

- The Mn slag dump.
- Raw material stockpile.
- Historical raw material dump.
- Mn slimes dam.

The manganese slag dump is considered the highest risk in terms of contaminant load to the receiving environment. A summary of the contaminant loads to the groundwater resource from the abovementioned sources are shown in **Table 2.1**.

The extent of possible groundwater contamination from the sources were assessed using the TDS and Mn concentrations. TDS provides an overall assessment of the groundwater quality at the site whereas Mn is related to the specific activities at Transalloys. The concentrations assigned to the individual sources is based on the previous detailed assessment of the slag dump that was conducted by Pulles, Howard and De Lange (PHD, 2008), as well as the recent studies by INFOTOX (Van Niekerk, 2018) for the Raw material storage area and the Historical raw material stockpile. In the absence of more detailed information, the source concentrations were estimated based on the average groundwater quality information.

The source concentrations for the waste disposal sites are highlighted below. The Mn slag dump is estimated at 15 mg/ℓ and the Raw Material Stockpile at 4.1 mg/ℓ. The Historical Raw Materials Dump is estimated at 9.03 mg/ℓ.

Table 2.1: Contaminant loads from primary sources at Transalloys

Rank 1 **Manganese slag dump** **- Operational since 1962** **- Unlined**	**Footprint**	281,500 m^2	
	Top (unsaturated)	161,446 m^2	
	Rainfall ingress	322 m^3/d	
	Runoff; Estimated 0%	0 m^3/d	
	Evaporation; Estimated 78%	251 m^3/d	
	Infiltration from top	**71 m^3/d**	
	Slope Area	120,054 m^2	
	Rainfall ingress	239 m^3/d	
	Runoff; Estimated 50%	120 m^3/d	
	Evaporation; Estimated 28%	67 m^3/d	
	Infiltration from slopes	**53 m^3/d**	
	Total Inflow	**124 m^3/d**	
	Recharge to aquifer; Estimated 3%	**3.71 m^3/d**	
	Potential Load	**Mn**	**TDS**
		15 mg/l	**1600 mg/l**
		0.0556 kg/d	**5.93 kg/d**
Rank 2 **Raw Material Stockpile** **- Operational** **- Unlined**	**Footprint**	120,800 m^2	
	Rainfall ingress	241 m^3/d	
	Recharge to aquifer; Estimated 3%	**3.71 m^3/d**	
	Potential Load	**Mn**	**TDS**
		4.1 mg/l	**800 mg/l**
		0.0296 kg/d	**5.78 kg/d**
Rank 3 **Historical Raw Material Dump** **- Operational since 1962** **- Unlined**	**Footprint**	89,920 m^2	
	Rainfall ingress	179 m^3/d	
	Recharge to aquifer; Estimated 3%	**5.38 m^3/d**	
	Potential Load	**Mn**	**TDS**
		9.03 mg/l	**800 mg/l**
		0.0486 kg/d	**4.30 kg/d**
Rank 4 **Manganese slimes dam** **- Operational since 1998** **- Unlined**	**Footprint area**	28,860 m^2	
	Top area (Total)	17,830 m^2	
	Top area (unsaturated 80% of surface)	14,264 m^2	
	Rainfall ingress	7 m^3/d	
	Runoff; Estimated 0%	0 m^3/d	
	Evaporation; Estimated 0%	0 m^3/d	
	Infiltration from unsaturated top	**6 m^3/d**	
	Top area (saturated 20% of surface)	3,556 m^2	
	Rainfall ingress	28 m^3/d	
	Runoff; Estimated 0%	0 m^3/d	
	Evaporation; Estimated 78%	22 m^3/d	
	Infiltration from saturated top	**7 m^3/d**	
	Slope Area	11,030 m^2	
	Rainfall volume	22 m^3/d	
	Runoff; Estimated 55%	12 m^3/d	
	Evaporation; Estimated 30%	7 m^3/d	
	Infiltration from slopes	**3 m^3/d**	
	Total Inflow	**17 m^3/d**	
	Recharge to aquifer; Estimated 3%	**0.5 m^3/d**	
	Potential Load	**Mn**	**TDS**
		3.48 mg/l	**650 mg/l**
		0.0017 kg/d	**0.33 kg/d**

The contaminant sources at Transalloys with a lower estimated risk include the following:

- Pollution control dam.
- Sewage evaporation ponds.
- Fe-Cr slimes dam.
- Cr Return water dam.

The calculated contaminant loads from these sources are summarised in **Table 2.2**.

Table 2.2: Contaminant loads from minor sources at Transalloys (J&W, 2016)

Source	Estimated Seepage Volume to Groundwater	Concentration		Load	
		Mn	TDS	Mn	TDS
	(m^3/d)	(mg/l)	(mg/l)	(kg/d)	(kg/d)
Pollution control dam Lined	0.13	1.28	556	0.0002	0.07
Sewage evaporation ponds Lined	0.19	0.38	350	0.0001	0.06
Mn Return Water Dam Operational since 1998 Lined	0.05	0.03	740	0.0000	0.04
Fe-Cr slimes dam Operational between 2006 - 2008 Lined	0.05	0.68	300	0.0000	0.02
Cr Return Water Dam Operational since 2006 Lined	0.00	0.01	1256	0.0000	0.00

The detailed waste assessment conducted previously indicated that the FSD is not considered a significant source of contamination and does not contribute significantly to the impact on the groundwater.

2.3 Description of the Groundwater Pathway

The conceptual geohydrological model was described in detail in previous reports (van Biljon, 2016 and 2018), but is again included in this report for ease of reference. The groundwater pathway is described under the following headings:

- Regional geology.
- Aquifer type.
- Aquifer parameters.
- Groundwater gradients and flow.

2.3.1 Regional Geology

The geology of the region is the controlling agent for aquifer development. The regional surface geology over the study area is presented as **Figure 2.2**. The regional geology in the area is characterised by the sedimentary rocks of the Karoo Supergroup, in particular the Dwyka and Ecca Groups. The Dwyka consists mainly of tillite and diamictite, whereas the Ecca consists of siltstone, shale and sandstone belonging to the Vryheid Formation.

The Dwyka sediments were deposited during late Carboniferous to early Permian times by glacial processes and the underlying rocks, particularly in the north, display well-developed striated glacial pavements in places. The group consists mainly of diamictite (tillite), which is generally massive with little jointing, but it may be stratified in places. The Dwyka diamictite consists of angular to rounded clasts of basement rock embedded in a clay and silt matrix. Individual clasts measure up to 3m in diameter. Subordinate rock types are conglomerate, sandstone, rhythmite and mudstone (both with and without dropstones). In certain parts of the basin the diamictite display distinctive ‘tombstone’ morphology as a result of selective weathering along axial-plane cleavage.

According to Tankard et. al. (1982) the Ecca Group (Vryheid Formation) overlies the Dwyka Formation gradationally and comprises predominantly clastic sediments deposited in an extensive landlocked basin experiencing only rare marine incursion. Steyn and Beukes (1977) described the lower Vryheid Formation as upwards-coarsening shale and sandstone cycles, which represent prograding deltaic environments. This in turn is overlain by upwards-fining sandstone and shale cycles, which are of a fluvial origin.

The coal beds, which were deposited in the back swamps of meandering river systems, cap the Lower Vryheid lithologies. The depositional environment is believed to be a dendritic channel system that resulted in the deposition of more arenaceous material in the active channels and mud and coal deposited on their floodplains. Channel closure led to the filling of channels by mud, the establishment of swamps and the deposition of coal beds within them. Similar deltaic and fluvial processes characterise the sediments overlying the coal seams, consisting mainly of alternating sequences of shale and sandstone. The more competent sandstone formations can result in localised hilly terrains. The surface and near surface lithologies comprise topsoil, weathered sandstone and some ferricrete. The latter is important as it generally forms an impermeable layer, affecting groundwater flow.

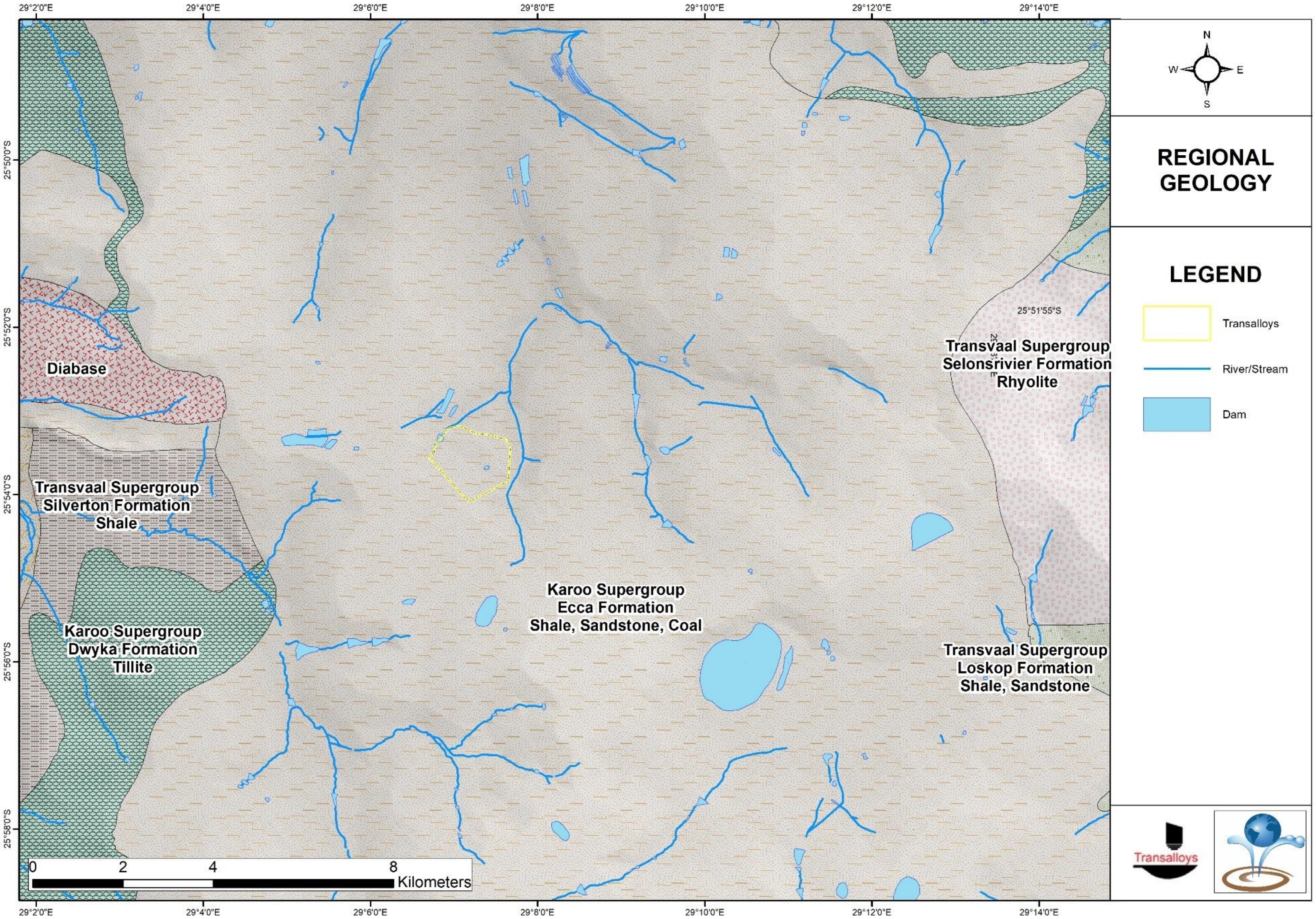


Figure 2.2: **Regional geology**

Dolerite intrusions are common in this type of geological terrain and represent the roots of the volcanic system and are presumed to be of the same age as the extrusive lavas (Fitch and Miller, 1984). The level of erosion that affected the Main Karoo basin has revealed the deep portions of the intrusive system, which displays a high degree of tectonic complexity.

The Karoo dolerite, which includes a wide range of petrological facies, consists of an interconnected network of dykes and sills and it is nearly impossible to single out any particular intrusive or tectonic event. It would, however, appear that a very large number of fractures were intruded simultaneously by magma and that the dolerite intrusive network acted as a shallow stock work-like reservoir. A geophysical study conducted by Rison in 2006, however, could not locate any dykes within the study area.

2.3.2 Aquifer Type

The aquifer development at the site is governed by the local geology. The local geology is based on previous drilling during 2006 and 2012 and can be summarised as follows (**Table 2.3):**

Table 2.3: Site geology and aquifer type (J&W, 2016)

Depth	Description	Aquifer Type
0 – 3m	Topsoil. Brown, sandy clay	Weathered Aquifer
3 – 9m	Sandstone. Weathered sandstone	
9 – 16m	Sandstone. Moderately weathered sandstone	Fractured Aquifer
16 – 30m	Shale. Moderately weathered to hard rock shale, with intercalated sandstone lenses. Carbonaceous in places and 1 – 3m thick coal seams	
30 – 60m	Sandstone. Hard rock sandstone	

At Transalloys the geology can be divided into two distinct aquifers (see **Table 2.2**), namely a shallow weathered aquifer and a deeper fractured aquifer. The monitoring boreholes aimed at separating the two aquifers and in some instances borehole pairs were drilled. A borehole pair consists of a shallow borehole (~10m – 15m deep) and a deep borehole (~30m – 60m deep) to investigate and monitor the two aquifers separately.

2.3.2.1. Weathered Aquifer

This aquifer mainly comprises unconsolidated sand and clay. The depth of weathering, based on the geological borehole logs and some field investigations varies between 0m – 16m in depth, with an average thickness of 9m.

Recharge to this aquifer occurs from rainfall as well as from surface water sources, including the Transalloys waste disposal sites.

Rainfall recharge to the aquifer is reportedly in the order of 1 – 3% of the mean annual precipitation (MAP) (Hodgson & Krantz, 1998). The characteristic shale layers in the Karoo lithology restrict the downward filtration of rainwater into the deeper formations. Groundwater therefore often accumulates on the contact between the weathered and “fresh” bedrock. The borehole yields in this aquifer are generally low due to the very low hydraulic conductivity (K) of the aquifer material and the limited vertical extent of this aquifer. The groundwater quality in undisturbed areas is good due to the dynamic recharge from rainfall. This shallow aquifer is, however, more likely to be impacted by surface contaminant sources such as the Transalloys waste disposal sites.

The weathered aquifer is incorporated into the numerical model as a distinct layer. The information regarding the depth of weathering is restricted to the immediate vicinity of the site, but it does, however, appear if there is a correlation between the topography and the weathering depth as illustrated in **Figure 2.3**.

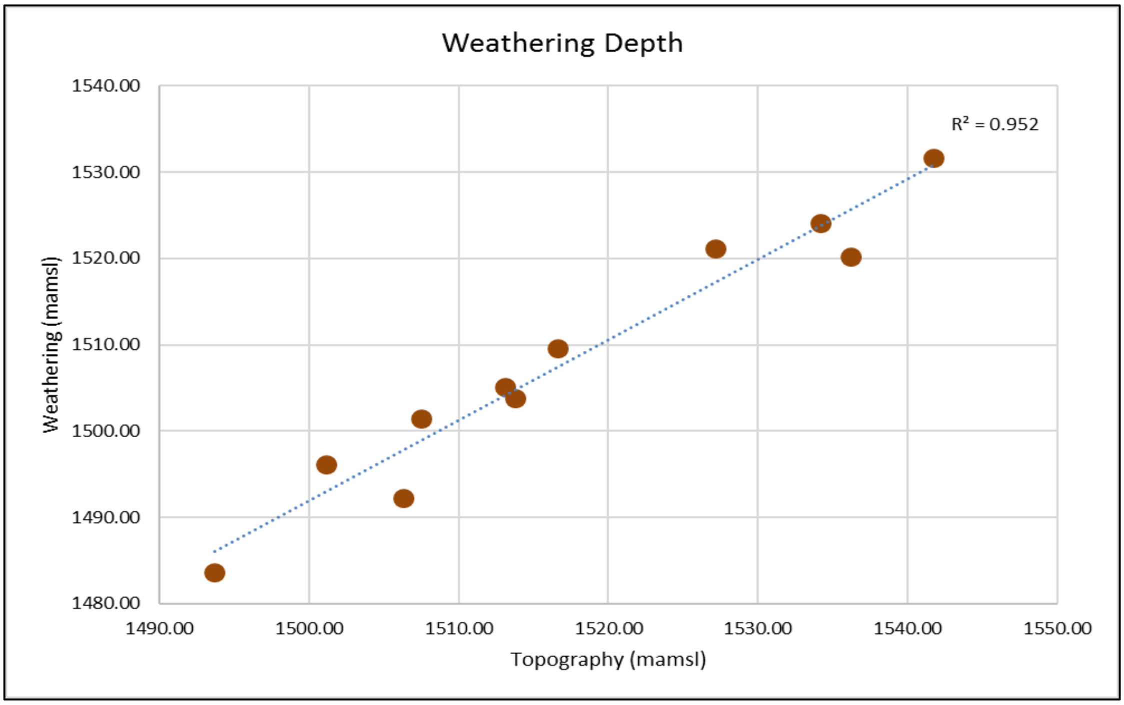


Figure 2.3: Correlation between weathering depth and topography

Based on this 95% correlation the weathering profile can be interpolated over a larger area for inclusion into the modelled area (**Figure 2.4**).

2.3.2.2. Fractured Aquifer

A deeper fractured aquifer is also present in the “fresh” shale, sandstone and coal seams underlying the weathered material. The primary porosity of the Ecca Group rocks does not allow significant groundwater flow, except where the porosity has been increased by subsequent secondary structures, such as faults and dykes. No dykes were, however, detected in the study area.

According to Hodgson and Krantz (1998) the coal seams often show the highest hydraulic conductivity. Where developed, the fractured Karoo aquifer seldom constitutes 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. This may be attributed to a less dynamic system and a larger residence time of rainfall recharge within the aquifer.

The boreholes did not fully penetrate the fractured aquifer and the thickness of the aquifer is not known. As a rule of thumb, the fractures generally close at depths of 50 – 60m below surface. For modelling purposes, a thickness of 50m for the fractured aquifer was assumed.

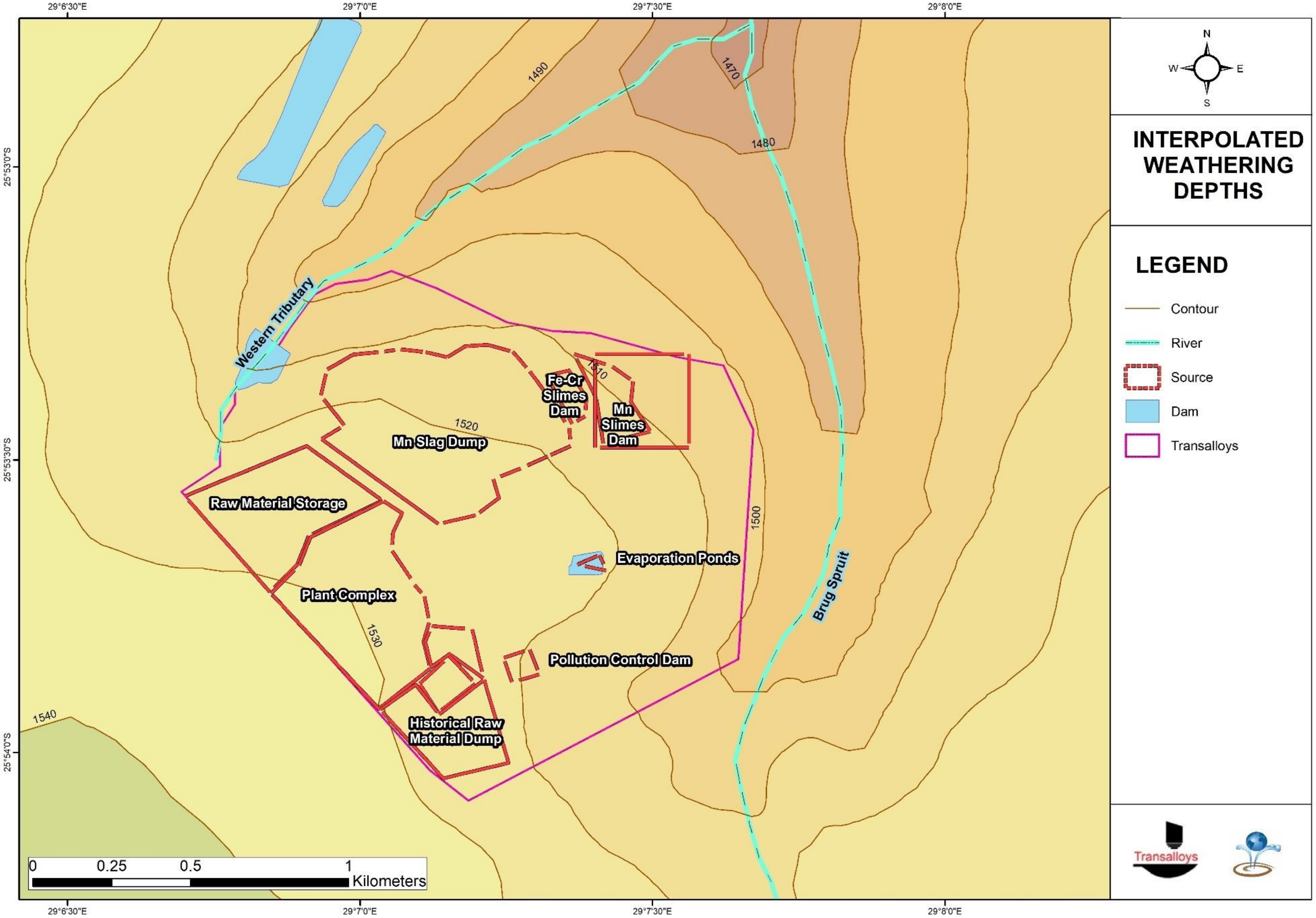


Figure 2.4: **Interpolated depth of weathering at Transalloys**

2.3.3 Aquifer Parameters

Eighteen (18) boreholes were tested at the site during the Rison (2006) and MVB (2012) studies. Aquifer tests were undertaken on the boreholes to calculate the transmissivity (T) and hydraulic conductivity (K). A summary of the calculated and estimated aquifer parameters in both aquifers are shown in **Table 2.4**. These parameters were used as the starting parameters during the model calibration.

The following geometric averages can be calculated from **Table 2.4**:

- Weathered Aquifer: Transmissivity = 0.48 m^2/day.

  Hydraulic conductivity = 0.08 m/day.
- Fractured Aquifer: Transmissivity = 0.55 m^2/day.

  Hydraulic conductivity = 0.03 m/day.
- Individual fractures: Transmissivity = 90.16 m^2/day.

  Hydraulic conductivity = 8.18 m/day.

A further eleven (11) boreholes were drilled in October 2018 to expand the monitoring network. These boreholes were, however, only tested for yield at the time of drilling and no data is available to calculate the aquifer parameters.

The borehole localities are shown in **Figure 2.10**. A distinction is made between the shallower, weathered aquifer (S) and the deeper fractured aquifer (D) monitoring.

Table 2.4: Aquifer parameter summary

BH No.	Date Drilled	Longitude	Latitude	Collar Elevation (mamsl)	Groundwater Table		Depth (m)	K (m/d)	T (m^2/d)	Description
					mbg	mamsl				
Shallow Weathered Aquifer										
RGC 2S	08/12/2005	29.12047	-25.8978	1527.31	6.31	1521.00	10	0.154	0.481	Down-gradient of coal stockpile
RGC 3S	08/12/2005	29.12113	-25.8961	1524.91	2.96	1521.95	10	0.359	2.177	Down-gradient of sewage effluent dam
RGC 7S	07/12/2005	29.12498	-25.8897	1512.52	4.98	1507.54	10	0.093	0.362	Down-gradient of the waste sites
RGC 8S	07/12/2005	29.11637	-25.8881	1520.00	2.84	1517.16	10	0.124	0.751	Down-gradient of the waste sites
RGC 9sS	08/12/2005	29.11815	-25.8842	1502.02	0.64	1501.38	10	1.371	10.66	Down-gradient of the Highveld Steel slimes dam
TA 1S	08/03/2012	29.12393	-25.8943	1527.19	4.04	1523.15	15	0.0055	0.061	Down-gradient of evaporation/oxidation ponds
TA 2S	09/03/2012	29.12668	-25.8935	1516.03	7.83	1508.20	16	0.0043	0.030	Down-gradient of evaporation/oxidation ponds
RBH 1A	October 2018	29.12125	-25.9004	1528.57	1.00	1527.57	30	Yield = 5.6 ℓ/sec		Down-gradient to monitor any plume development towards Clewer
RBH 4S	October 2018	29.12228	-25.8973	1523.25	6.00	1517.25	30	Yield = 3.0 ℓ/sec		Down-gradient of pollution control dam
RBH 5S	October 2018	29.12832	-25.8902	1500.00	1.50	1498.50	30	Yield = 4.2 ℓ/sec		Down-gradient to monitor any plume development towards Brugspruit
Deeper Fractured Aquifer										
RGC 1	08/12/2005	29.11737	-25.9002	1537.07	7.15	1529.92	30	0.420	0.955	Receiving water quality up-gradient of plant
RGC 2D	08/12/2005	29.12047	-25.8978	1527.31	6.05	1521.26	30	0.012	0.263	Down-gradient of coal stockpile
RGC 3D	08/12/2005	29.12113	-25.8961	1524.91	4.12	1520.79	30	0.027	0.318	Down-gradient of sewage effluent dam
RGC 5	07/12/2005	29.12612	-25.8835	1497.83	5.88	1491.95	30	0.070	1.642	Further down-gradient to monitor any plume development
RGC 6	07/12/2005	29.11995	-25.8852	1507.76	10.71	1497.05	30	0.090	1.732	Further down-gradient to monitor any plume development
RGC 8D	07/12/2005	29.11638	-25.8881	1520.00	3.03	1516.97	30	0.010	0.249	Down-gradient of the waste sites
TA 1D	08/03/2012	29.12393	-25.8943	1527.19	6.90	1520.29	60	0.0015	0.078	Down-gradient of evaporation/oxidation ponds
TA 2D	09/03/2012	29.12668	-25.8935	1516.03	9.60	1506.43	45	0.055	1.930	Down-gradient of evaporation/oxidation ponds
RBH 1B	October 2018	29.12125	-25.9004	1528.57	1.50	1527.07	65	Yield = 5.2 ℓ/sec		Down-gradient to monitor any plume development towards Clewer
RBH 1C	October 2018	29.11488	-25.8911	1522.05	5.00	1517.05	65	Yield = 4.5 ℓ/sec		Down-gradient to monitor any plume development towards Western Tributary
RBH 2	October 2018	29.11358	-25.8917	1524.59	-	-	65	Not tested		Down-gradient to monitor any plume development towards Western Tributary
RBH 3	October 2018	29.12302	-25.8875	1510.93	2.50	1508.43	65	Yield = 5.9 ℓ/sec		Further down-gradient to monitor any plume development

BH No.	Date Drilled	Longitude	Latitude	Collar Elevation (mamsl)	Groundwater Table		Depth (m)	K (m/d)	T (m²/d)	Description
					mbg	mamsl				
RBH 4D	October 2018	29.12225	-25.8972	1523.25	5.50	1517.75	65	Yield = 1.95 ℓ/sec		Down-gradient of pollution control dam
RBH 5D	October 2018	29.12832	-25.8902	1500.00	2.00	1498.00	65	Yield = 4.5 ℓ/sec		Down-gradient to monitor any plume development towards Brugspruit
RBH 6	October 2018	29.1117	-25.8926	1527.04	-	-	65	Not tested		Down-gradient to monitor any plume development towards Western Tributary
RBH 7	October 2018	29.11967	-25.9008	1531.58	8.00	1523.58	30	Yield = 2.3 ℓ/sec		Down-gradient to monitor any plume development towards Clewer
Individual fractures										
RGC 4	07/12/2005	29.1273	-25.8903	1503.81	2.92	1500.89	30	5.712	149.18	Further down-gradient to monitor any plume development
RGC 7D	07/12/2005	29.12498	-25.8897	1512.52	4.66	1507.86	30	8.994	212.98	Down-gradient of the waste sites
RGC 9D	08/12/2005	29.11815	-25.8842	1502.02	16.95	1485.07	30	1.700	23.07	Down-gradient of the Highveld Steel slimes dam

Note: *Groundwater level at the time of testing.*

Boreholes drilled in 2018 were tested to determine the yield (ADA Drilling for Master Spaces Real Projects (Pty) Ltd, 2018). Data not available to calculate aquifer parameters.

2.3.4 Groundwater Gradients and Flow

The groundwater levels in the monitoring boreholes are measured on a quarterly basis. **Table 2.5** provides a summary of the groundwater table at Transalloys.

Table 2.5: Groundwater levels

BH No.	Approximate Collar Elevation (mamsl)	Groundwater Level			
		Original (mbg)	Original (mamsl)	9th March 2021 (mbg)	9th March 2021 (mamsl)
Mn Slag Dump and Fe-Cr and Mn Slimes & Return Water Dams					
BH1	1514.32	Unknown	Unknown	8.54	1505.78
BH2	1514.18	Unknown	Unknown	9.26	1504.92
BH3	1513.91	Unknown	Unknown	6.09	1507.82
BH4	1517.62	Unknown	Unknown	6.83	1510.79
RBH3	1500.00	5.18	1494.82	5.08	1494.92
RGC4	1507.46	2.92	1500.89	3.41	1504.05
RBH5s	1528.58	1.50	1527.08	1.07	1527.51
RBH5d	1528.58	1.45	1527.13	0.70	1527.88
RGC7s	1513.10	4.98	1508.12	6.63	1506.47
RGC7d	1513.10	4.66	1507.86	6.67	1506.43
RGC8s	1513.80	2.84	1510.96	2.25	1511.55
RGC8d	1513.80	3.03	1516.97	2.41	1511.39
Raw Material Stockpile					
RBH1C	1522.09	2.14	1519.95	1.75	1520.34
RBH2	1511.66	1.45	1510.21	0.94	1510.72
RBH6	1527.10	5.92	1521.18	2.28	1524.82
Plant Complex					
RGC3s	1534.14	2.96	1531.18	Dry	-
RGC3d	1534.14	4.12	1520.79	5.10	1529.04
Historical Raw Materials Dump					
RGC2s	1536.17	6.31	1529.86	5.21	1530.96
RGC2d	1536.17	6.05	1521.26	5.23	1530.94
RBH7	1531.86	Unknown	Unknown	4.47	1527.39
RBH1A	1524.76	4.39	1520.37	4.10	1520.66
RBH1B	1524.76	4.45	1520.31	4.20	1520.56
Pollution Control Dam					
RBH4s	1523.22	3.73	1519.49	2.60	1520.62
RBH4d	1523.22	3.20	1520.02	2.60	1520.62
Sewage Evaporation Ponds					
TA1s	1527.22	4.04	1523.18	6.45	1520.77
TA1d	1527.11	6.90	1520.29	3.11	1524.00
TA2s	1516.63	7.83	1508.80	5.28	1511.35
TA2d	1516.58	9.60	1506.43	6.41	1510.17
Highveld Steel Slimes and Return Water Dams					
RGC9s	1506.31	0.64	1505.67	1.67	1504.64
RGC9d	1506.31	16.95	1485.07	1.87	1504.44

BH No.	Approximate Collar Elevation (mamsl)	Groundwater Level			
		Original (mbg)	Original (mamsl)	9th March 2021 (mbg)	9th March 2021 (mamsl)
Other Boreholes					
RGC 1	1541.69	7.15	1529.92	6.45	1535.24
RGC5	1493.67	5.88	1491.95	6.01	1487.66
RGC6	1501.13	10.71	1497.05	5.78	1495.35

Note: mbs = metres below surface
mamsl = metres above mean sea level

An important aspect when evaluating the geohydrological regime and groundwater flow mechanisms is the groundwater gradients. Groundwater flow within the study area is mainly controlled by the geology and it is known that in these geological terrains the groundwater generally mimics the topography. The groundwater levels in the monitoring boreholes were evaluated to prove that this concept is valid within the study area. The borehole collar elevations (representing the topography) were plotted against the groundwater elevation, as measured in the borehole. Figure **2.5** and **Figure 2.6** show that there is a 98% correlation in the weathered as well as the fractured aquifers.

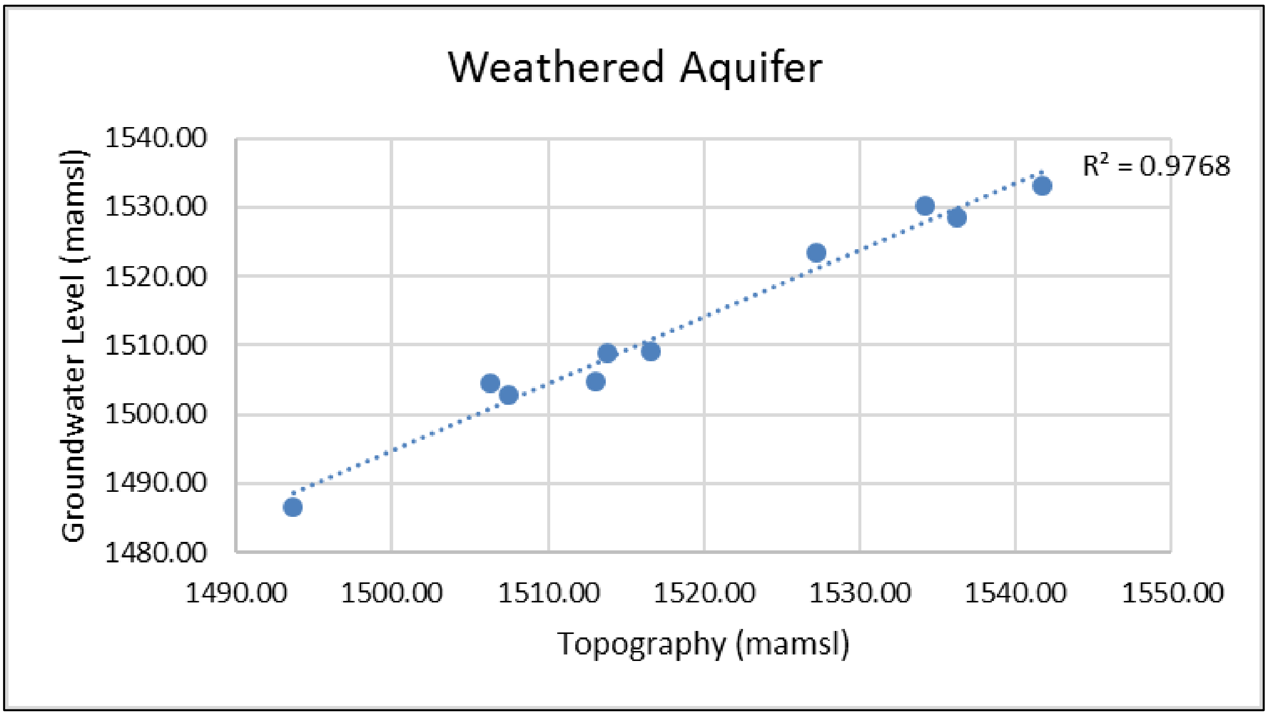


Figure 2.5: **Correlation between groundwater table and topography – Weathered aquifer**

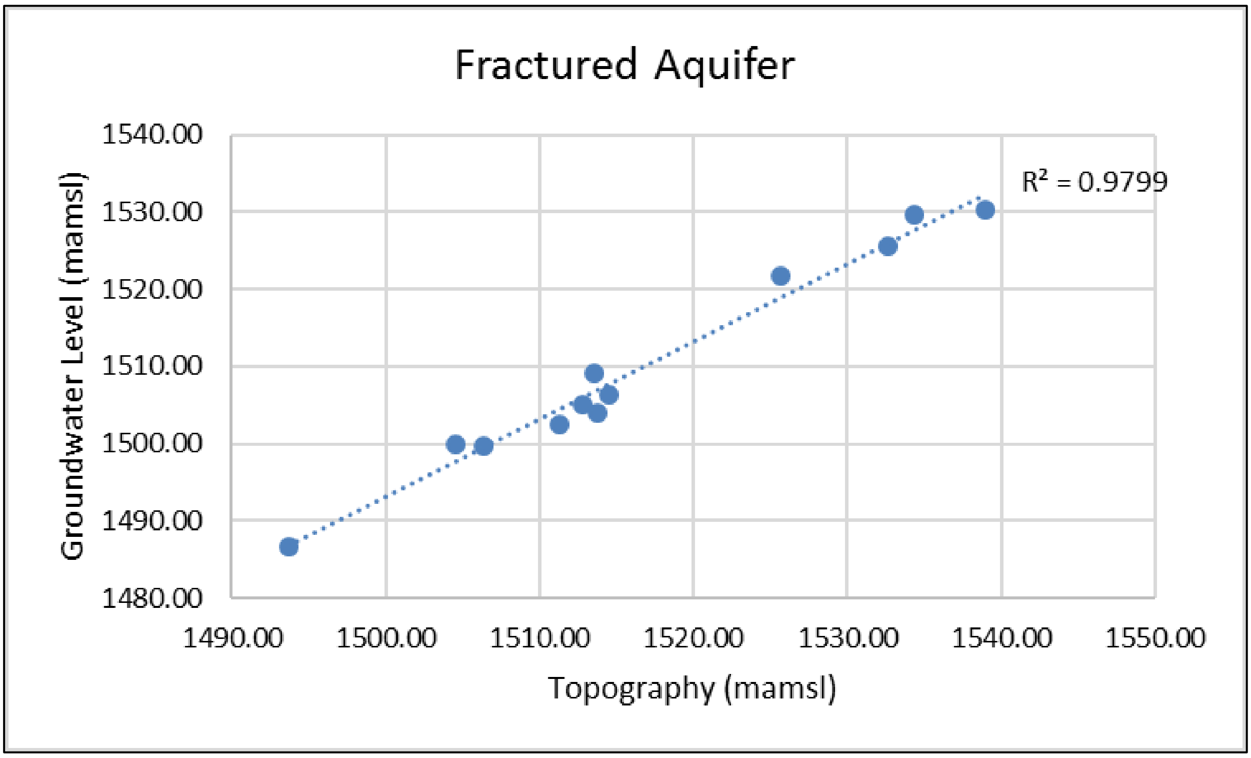


Figure 2.6: **Correlation between groundwater table and topography – Fractured aquifer**

Based on the assumption that the groundwater mimics the topography, the regional groundwater table can be extrapolated using the Bayesian interpolation. The regional interpolated groundwater gradients are presented in **Figure 2.7**.

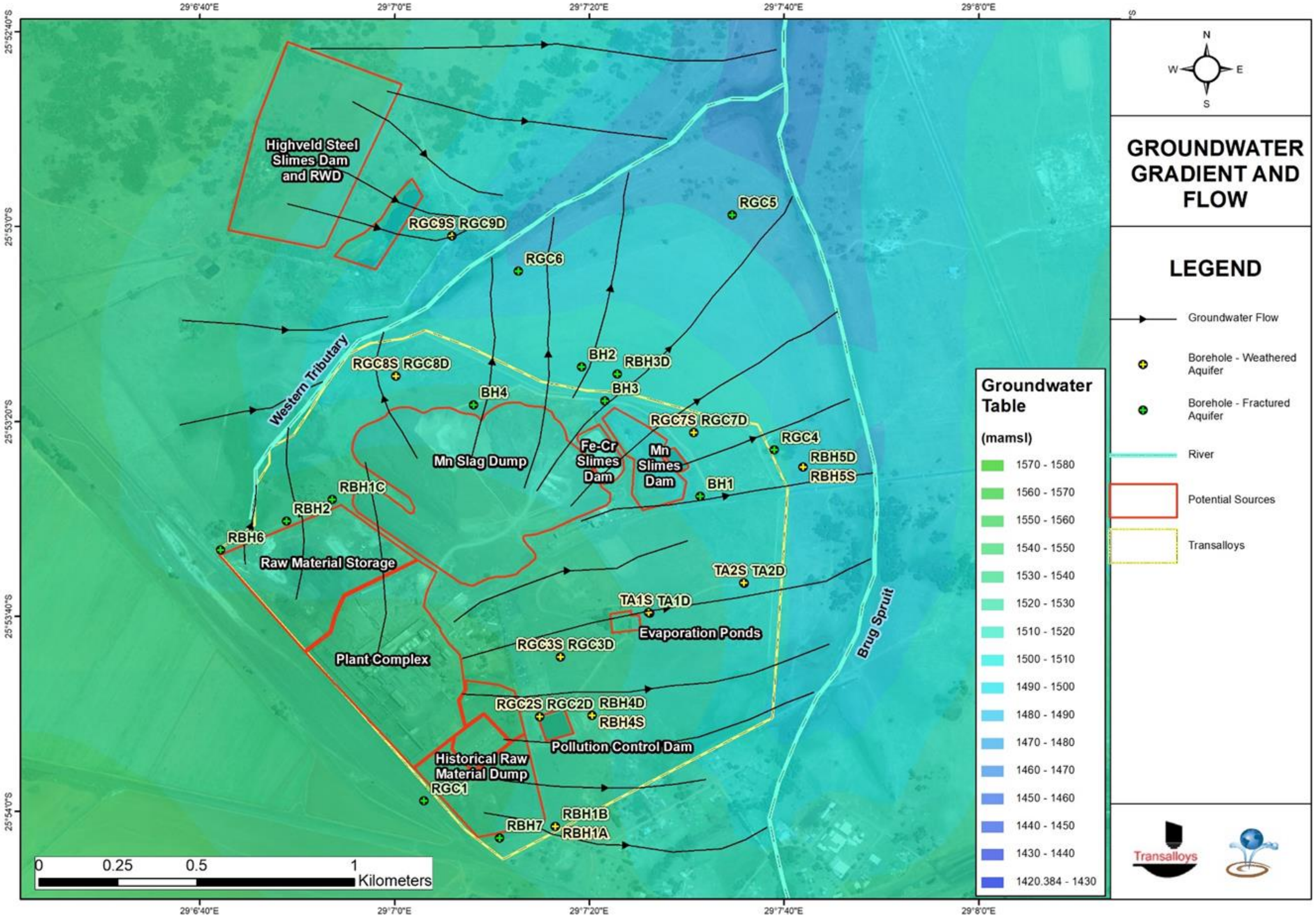


Figure 2.7: **Interpolated groundwater table at Transalloys**

2.4 Description of the Receptor

2.4.1 Land Use

The land use in the immediate vicinity of the study area consists mainly of mining, industrial and urban development, as well as some agriculture.

Within the study area the surface and groundwater drainage is towards the east and south-east, into the Brugspruit and its tributary, referred to as the Western Tributary (see **Figure 2.7**). The topography is undulating and gently slopes towards the Brugspruit.

These streams are considered the only receptors to impact from Transalloys, as there are no groundwater users downstream from the site.

2.4.2 Hydrochemistry

The water monitoring programme and chemistry results of the Transalloys site was investigated to understand the current conditions at the site, as well as to provide a chronological evaluation pertaining to the plume movement of identified contaminants. This has given insights on the movement of certain identified contaminants with regards to the downstream impact that could be expected. This review included:

- Groundwater; and
- Surface water.

2.4.2.1. Surface Water

The surface water monitoring points can be separated into natural water, which is the Brugspruit and the Western tributary, and the on-site water. The latter is referred to as industrial water and includes water in the pollution control dams (PCD) and return water dams (RWD). It also includes samples from the drinking water, water from the change house and water used for dust suppression. There are sixteen (16) surface water monitoring sites (**Table 2.6**).

Table 2.6: Surface water monitoring

ID	X	Y	Description
Natural Water			
S1	29.12751700	-25.90100000	Brugspruit - Clewer U/S on Brugspruit
S2	29.13036700	-25.89041700	Brugspruit - Road bridge
S3	29.11190000	-25.89196700	Brugspruit - Dam (U/S on tributary)
S4	29.12415000	-25.88108300	Brugspruit - Foot bridge / D/S Tributary
S5	29.12768300	-25.87586700	Brugspruit – confluence with tributary
Industrial Water			
S6	29.12018300	-25.89611700	NRWD - Inlet
S7	29.11873300	-25.89620000	Inlet to storm water dam
S8	29.11783300	-25.89811700	Water dewatered / Dust suppression
S9	29.11853300	-25.89501700	Transalloys Change House
S10	29.11900000	-25.89446700	Transalloys Admin
S11	29.12323300	-25.89505000	Transalloys Pond
S12	29.12278300	-25.89143300	TMR Municipal Drinking Water
S13	29.12463300	-25.89028300	RW Manganese RWD
S14	29.12245000	-25.88863300	Transalloys Chrome RWD
S15	29.12248300	-25.88890000	Drain to Transalloys Chrome RWD
S16	29.12488300	-25.89086700	Drain to Manganese RWD

The current surface water sampling localities are shown in **Figure 2.8**. The down-gradient receptors at Transalloys are the Brug Spruit and the Western Tributary. The risk within these streams is primarily to livestock drinking the water. Due to these risks the surface and groundwater chemistry are compared to the DWAF (1996) Livestock Watering Guidelines (**Table 2.7**) and the Olifants Catchment Resource Quality Objectives (RQO).

Table 2.7: Water quality guidelines

Macro-determinants	**Units**	**Livestock Watering DWAF (1996)**	**Olifants Catchment Resource Quality Objectives (RQO)**
pH	pH units	No Guideline	No Guideline
Total Alkalinity	mg/ℓ	No Guideline	>60
Electrical Conductivity (EC)	mS/m	No Guideline	111
Total Dissolved Solids (TDS)	mg/ℓ	1 000	No Guideline
Ca, Calcium	mg/ℓ	1 000	No Guideline
Cl, Chloride	mg/ℓ	1 500	No Guideline
SO_4, Sulphate	mg/ℓ	1 000	500
NO_3, Nitrate	mg/ℓ	100	4
F, Fluoride	mg/ℓ	2	3
Na, Sodium	mg/ℓ	2 000	No Guideline
K, Potassium	mg/ℓ	No Guideline	No Guideline
Mg, Magnesium	mg/ℓ	500	No Guideline
Zn, Zinc	mg/ℓ	20	0.036
Micro-determinants			
As, Arsenic	mg/ℓ	1	0.13
B, Boron	mg/ℓ	5	No Guideline
Ba, Barium	mg/ℓ	No Guideline	No Guideline
Al, Aluminium	mg/ℓ	5	0.15
Fe, Iron	mg/ℓ	10	No Guideline
Mn, Manganese	mg/ℓ	10	1.30
Co, Cobalt	mg/ℓ	1	No Guideline
Cr_{Total}, Chromium Total	mg/ℓ	No Guideline	No Guideline
Cr (VI), Chromium (VI)	mg/ℓ	1	No Guideline
Cu, Copper	mg/ℓ	0.5	0.008
Hg, Mercury	mg/ℓ	1	0.0017
Ni, Nickel	mg/ℓ	1	No Guideline
Cd, Cadmium	mg/ℓ	0.01	0.005
Mo, Molybdenum	mg/ℓ	0.01	No Guideline
Pb, Lead	mg/ℓ	0.1	0.013
Sb, Antimony	mg/ℓ	No Guideline	No Guideline
Se, Selenium	mg/ℓ	50	0.03
V, Vanadium	mg/ℓ	1	No Guideline

The water samples are collected and analysed by Yanka Laboratories (Pty) Ltd. A summary of the important chemical parameters is provided in **Table 2.8**. Samples that exceed the DWAF (1196) Livestock Watering guidelines are highlighted in red.

The inorganic chemical natural surface water (Brugspruit and Western Tributary) quality is generally good and none of the parameters exceed the guideline limits for livestock watering (DWAF, 1996). The industrial water qualities are generally slightly poorer and exceed the guideline limits in some instances. These waters are, however, in a closed circuit and is not discharged into the natural environment. **Figure 2.9** provides an overview of the surface water quality at the different sampling points. The distribution of the Manganese concentrations, compared to the guideline limits, is shown. The actual concentrations during July 2021 are shown in red.

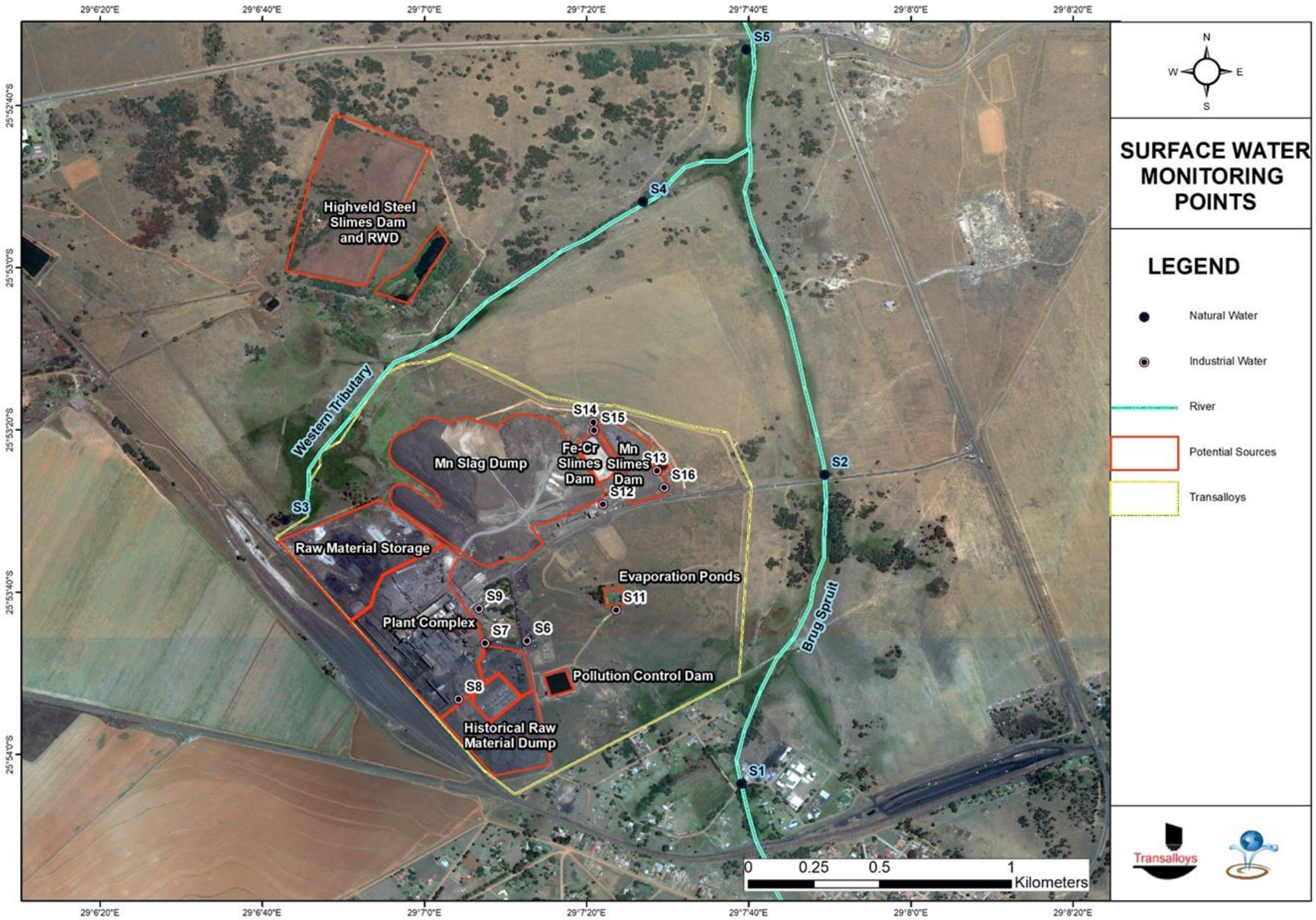


Figure 2.8: **Surface water sample localities**

Table 2.8: Current surface water quality at the Transalloys site

Parameter	Unit	Guidelines		S1	S2	S3	S4	S5	S6	S7	S8	S11	S13	S14	S15	S16
		DWAF (1996)	Olifants RQO	9/7/2021	9/7/2021	9/7/2021	9/7/2021	9/7/2021	9/7/2021	9/7/2021	9/7/2021	9/7/2021	9/7/2021	9/7/2021	9/7/2021	9/7/2021
				Natural Water					Industrial Water							
pH		-	-	5.86	5.95	6.21	6.97	7.03	6.94	7.03	7.07	6.88	10.00	9.69	10.00	9.16
EC	(mS/m)	-	111	50	61	67	67	66	126	103	105	85	114	123	128	109
TDS	(mg/ℓ)	1 000	-	279	352	428	420	392	832	675	672	445	682	833	863	702
Alk.	(mg/ℓ)	-	>60	74	51	44	37	71	148	144	149	257	89	71	87	38
Cl	(mg/ℓ)	1 500	-	30	53	32	31	43	69	74	70	49	42	42	43	41
SO$_4$	(mg/ℓ)	1 000	500	115	154	229	230	164	403	296	295	64	348	453	470	386
NO$_3$	(mg/ℓ)	100	4	0.60	0.57	1.07	1.00	3.35	<0.35	<0.35	<0.35	<0.35	<0.35	0.47	0.38	0.45
NH$_4$	(mg/ℓ)	-	-	1.27	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	36.90	0.58	0.59	<0.45	<0.45
F	(mg/ℓ)	2	3	0.27	0.16	0.21	0.22	0.40	1.45	1.28	1.33	0.34	0.92	1.76	1.76	1.64
Ca	(mg/ℓ)	1 000	-	30.80	23.80	48.50	48.70	34.10	64.60	53.60	57.70	34.90	92.78	129.00	133.00	98.10
Mg	(mg/ℓ)	500	-	19.70	17.30	14.80	15.30	16.30	47.30	34.30	36.80	20.90	3.73	0.91	0.13	3.21
Na	(mg/ℓ)	2 000	-	28.30	54.10	47.00	42.50	54.20	95.20	86.40	85.40	42.90	59.88	66.40	66.60	64.20
K	(mg/ℓ)	-	-	6.31	16.30	25.50	25.60	22.30	62.50	33.10	35.50	16.30	79.87	93.80	94.20	82.50
Fe	(mg/ℓ)	10	-	0.08	0.11	<0.01	<0.01	<0.01	0.07	0.33	0.39	0.09	<0.01	<0.01	<0.01	<0.01
Mn	(mg/ℓ)	10	1.3	0.02	<0.01	<0.01	0.04	<0.01	0.08	9.92	<0.01	2.34	<0.01	<0.01	<0.01	0.02

	Sample description
S1	Brugspruit - Clewer U/S on Brugsruit (S1)
S2	Brugspruit - Road bridge (S2)
S3	Brugspruit - Dam (U/S on tributary) (S3)
S4	Brugspruit - Foot bridge / D/S Tributary (S4)
S5	Brugspruit – Confluence (S5)
S6	NRWD - Inlet (S6)
S7	Inlet to storm water dam (S7)
S8	Water dewatered / Dust suppression (S8)
S11	Transalloys Pond (S11)
S13	RW Manganese RWD (S13)
S14	Transalloys Chrome R.W.D (S14)
S15	Drain to Transalloys Chrome RWD (S15)
S16	Drain to Manganese RWD (S16)

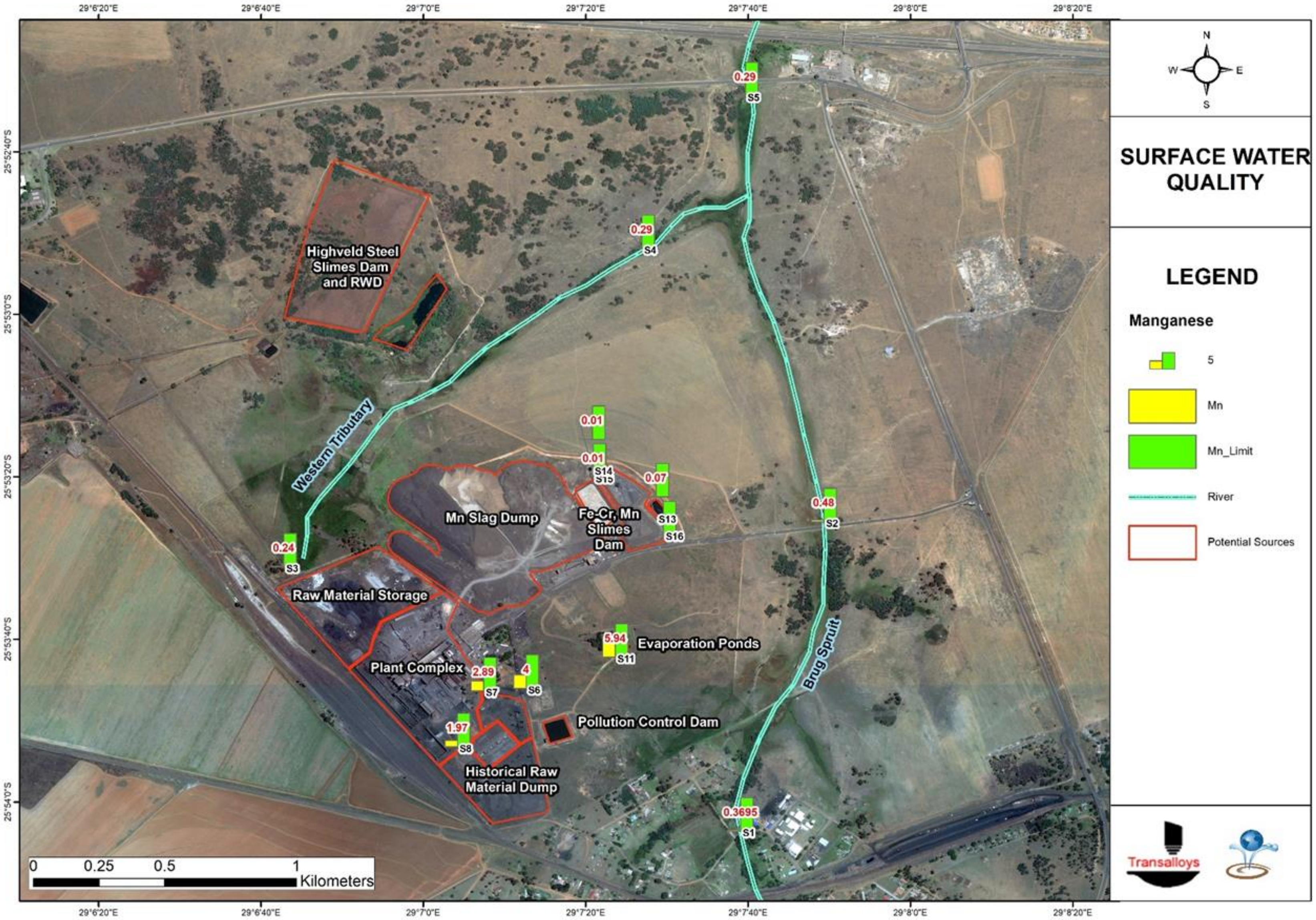


Figure 2.9: **Mn distribution in the surface water sampling points – July 2021**

2.4.2.2. Groundwater

At Transalloys the geology can be divided into two distinct aquifers, namely a shallow weathered aquifer and a deeper fractured aquifer. The monitoring boreholes aimed at separating the two aquifers and in some instance's borehole pairs were drilled. A borehole pair consists of a shallow borehole (~10m – 15m deep) and a deep borehole (~30m – 60m deep) to investigate and monitor the two aquifers separately.

- **Weathered Aquifer:** This aquifer mainly comprises unconsolidated sand and clay. The depth of weathering, based on the geological borehole logs and some field investigations varies between 0m – 16m in depth, with an average thickness of 9m. Recharge to this aquifer occurs from rainfall as well as from surface water sources, including the Transalloys waste disposal sites.
- **Fractured Aquifer:** A deeper fractured aquifer is also present in the "fresh" shale, sandstone and coal seams underlying the weathered material. The primary porosity of the Ecca Group rocks does not allow significant groundwater flow, except where the porosity has been increased by subsequent secondary structures, such as faults and dykes. No dykes were, however, detected in the study area. Where developed, the fractured Karoo aquifer seldom constitutes 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. This may be attributed to a less dynamic system and a larger residence time of rainfall recharge within the aquifer.

There are several boreholes on the Transalloys property that were drilled during various investigations. Most of the boreholes consists of pairs that monitors the weathered and fractured aquifers separately.

The following types of boreholes are present on the property:

- ***Background borehole:*** A background borehole is located up-gradient from the contaminant source/s and monitors the receiving water quality. Such a borehole is unaffected by contamination and should be used to compare the down-gradient water qualities and assess the impact from a source. Borehole RGC 01.
- ***Source borehole:*** A source borehole is located at the down-gradient edge of a contaminant source. The purpose of such a borehole is to assess the contaminant load from the source that enters the aquifer/s. These boreholes are typically contaminated and represents the worst quality. Boreholes RGC 02, RGC 07, TA 1, RBH1A, B, C, RBH 4s / 4d and RBH 5s / 5d.
- ***Plume borehole:*** A plume borehole is located some distance from the source and is used to determine the rate of contaminant migration. These boreholes may or may not be impacted on dependent on the groundwater and contaminant flow velocities. Boreholes RGC 03, RGC 04, RGC 08, RGC 09, BH 3, BH 4, and RBH 02.
- ***Compliance borehole:*** A compliance borehole is located at the boundary of the property or at a receptor such as a surface stream. The primary aim is to monitor if down-gradient receptors (groundwater users and surface water bodies) are impacted on. These boreholes must comply with the Water Use Licence conditions. Boreholes RGC 05, RGC 06, TA 2 and RBH 5s / 5d.

Figure 2.10 shows the locality of the boreholes in relation to the various waste sites. The borehole purpose is summarised in **Table 2.9**.

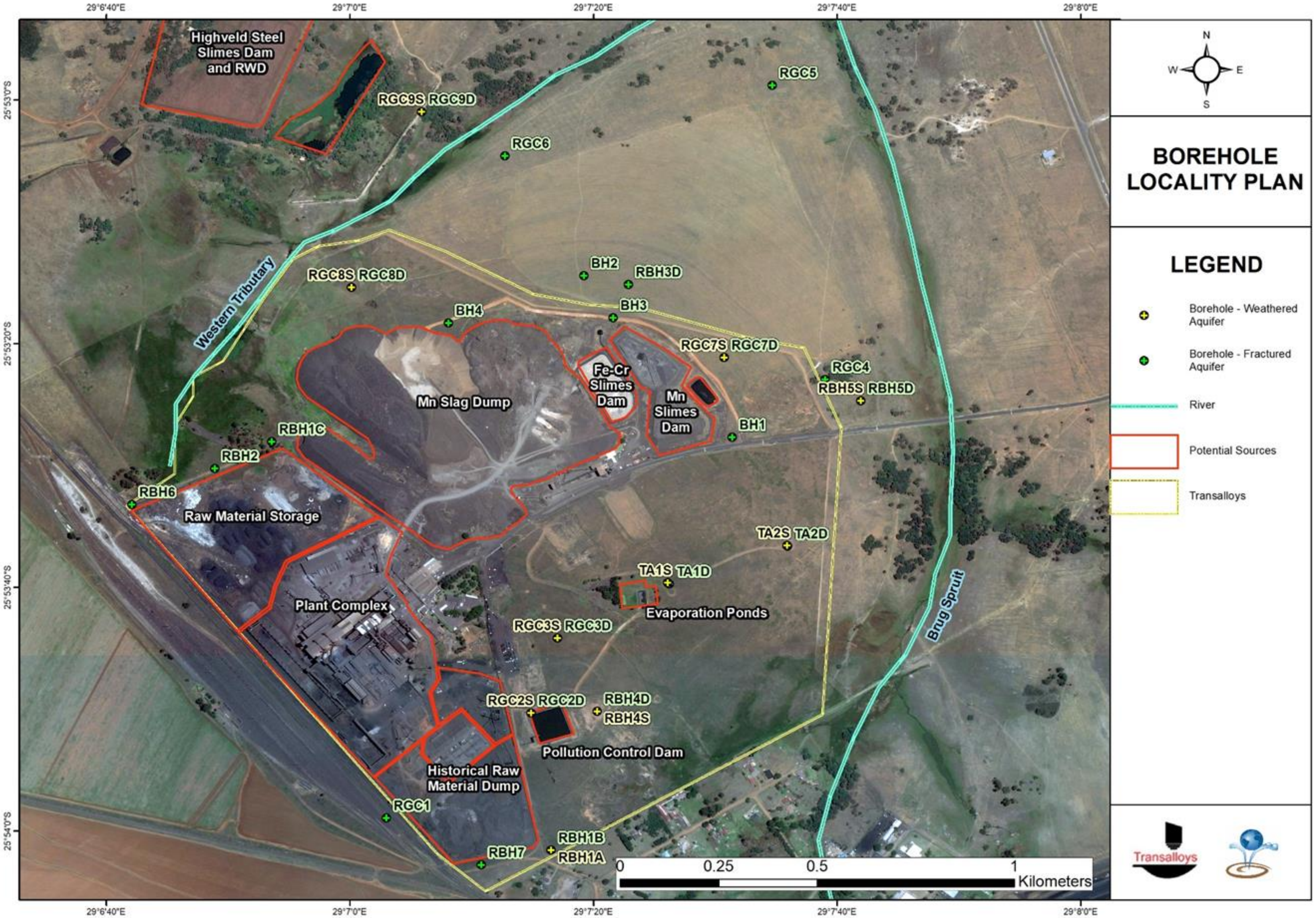


Figure 2.10: Monitoring borehole locality plan

Table 2.9: Monitoring borehole summary

Bh No.	Date Drilled	Latitude	Longitude	Approximate Collar Elevation (mamsl)	Groundwater Level		Depth (m)	Purpose
					mbg	mamsl		
Mn Slag Dump and Fe-Cr and Mn Slimes & Return Water Dams								
BH 1	Unknown	25°53'27.66"S	29° 7'31.38"E	1514.32				Source borehole - **Fractured Aquifer**
BH 2	Unknown	25°53'14.40"S	29° 7'19.20"E	1514.18				Plume borehole - **Fractured Aquifer**
BH 3	Unknown	25°53'17.88"S	29° 7'21.60"E	1513.91				Source borehole - **Fractured Aquifer**
BH 4	Unknown	25°53'18.30"S	29° 7'8.10"E	1517.62				Source borehole - **Fractured Aquifer**
RBH 3	2018	25°53'15.12"S	29° 7'22.86"E	1500.00	5.18	1494.82	65	Plume borehole - **Fractured Aquifer**
RGC 4	07/12/2005	25°53'22.92" S	29°07'39.00" E	1507.46	2.92	1500.89	30	Plume borehole - **Fractured Aquifer**
RBH 5S	2018	25°53'24.66"S	29° 7'41.94"E	1528.58	1.50	1527.08	30	Plume borehole - **Weathered Aquifer**
RBH 5D	2018	25°53'24.66"S	29° 7'41.94"E	1528.58	1.45	1527.13	65	Plume borehole - **Fractured Aquifer**
RGC 7S	07/12/2005	25°53'21.12" S	29°07'30.72" E	1513.10	4.98	1508.12	10	Source borehole - **Weathered Aquifer**
RGC 7D	07/12/2005	25°53'21.12" S	29°07'30.72" E	1513.10	4.66	1507.86	30	Source borehole - **Fractured Aquifer**
RGC 8S	07/12/2005	25°53'15.36" S	29°07'00.12" E	1513.80	2.84	1510.96	10	Plume borehole - **Weathered Aquifer**
RGC 8D	07/12/2005	25°53'15.36" S	29°07'00.12" E	1513.80	3.03	1516.97	30	Plume borehole - **Fractured Aquifer**
Raw Material Stockpile								
RBH 1C	2018	25°53'28.02"S	29° 6'53.58"E	1522.09	2.14	1519.95	65	Source borehole - **Fractured Aquifer**
RBH 2	2018	25°53'30.24"S	29° 6'48.90"E	1511.66	1.45	1510.21	65	Source borehole - **Fractured Aquifer**
RBH 6	2018	25°53'33.18"S	29° 6'42.12"E	1527.10	5.92	1521.18		Source borehole - **Fractured Aquifer**
Plant Complex								
RGC 3S	08/12/2005	25°53'44.16" S	29°07'17.04" E	1534.14	2.96	1531.18	10	Plume borehole - **Weathered Aquifer**
RGC 3D	08/12/2005	25°53'44.16" S	29°07'17.04" E	1534.14	4.12	1520.79	30	Plume borehole - **Fractured Aquifer**
Historical Raw Materials Dump								
RGC 2S	08/12/2005	25°53'50.28" S	29°07'14.88" E	1536.17	6.31	1529.86	10	Source borehole - **Weathered Aquifer**
RGC 2D	08/12/2005	25°53'50.28" S	29°07'14.88" E	1536.17	6.05	1521.26	30	Source borehole - **Fractured Aquifer**
RBH 7	2018	25°54'2.76"S	29° 7'10.80"E	1531.86				Source borehole - **Fractured Aquifer**

Bh No.	Date Drilled	Latitude	Longitude	Approximate Collar Elevation (mamsl)	Groundwater Level		Depth (m)	Purpose
					mbg	mamsl		
RBH 1A	2018	25°54'1.56"S	29° 7'16.50"E	1524.76	4.39	1520.37	30	Compliance borehole - **Weathered Aquifer**
RBH 1B	2018	25°54'1.56"S	29° 7'16.50"E	1524.76	4.45	1520.31	65	Compliance borehole - **Fractured Aquifer**
Pollution Control Dam								
RBH 4S	2018	25°53'50.22"S	29° 7'20.22"E	1523.22	3.73	1519.49	30	Source borehole - **Weathered Aquifer**
RBH 4D	2018	25°53'49.74"S	29° 7'20.10"E	1523.22	3.20	1520.02	65	Source borehole - **Fractured Aquifer**
Sewage Evaporation Ponds								
TA 1S	08/03/2012	25°53'39.59" S	29°07'26.08" E	1527.22	4.04	1523.18	15	Source borehole - **Weathered Aquifer**
TA 1D	08/03/2012	25°53'39.70" S	29°07'26.22" E	1527.11	6.90	1520.29	60	Source borehole - **Fractured Aquifer**
TA 2S	09/03/2012	25°53'36.56" S	29°07'35.87" E	1516.63	7.83	1508.80	15	Plume borehole - **Weathered Aquifer**
TA 2D	09/03/2012	25°53'36.60" S	29°07'35.90" E	1516.58	9.60	1506.43	45	Plume borehole - **Fractured Aquifer**
Highveld Steel Slimes and Return Water Dams								
RGC 9D	08/12/2005	25°53'00.96" S	29°07'05.88" E	1506.31	0.64	1505.67	10	Source borehole - **Weathered Aquifer**
RGC 9D	08/12/2005	25°53'00.96" S	29°07'05.88" E	1506.31	16.95	1485.07	30	Source borehole - **Fractured Aquifer**
Other Boreholes								
RGC 1	08/12/2005	25°53'58.92" S	29°07'03.00" E	1541.69	7.15	1529.92	30	Background borehole - **Fractured Aquifer**
RGC 5	07/12/2005	25°52'58.80" S	29°07'34.68" E	1493.67	5.88	1491.95	30	Compliance borehole - **Fractured Aquifer**
RGC 6	07/12/2005	25°53'04.56" S	29°07'12.72" E	1501.13	10.71	1497.05	30	Compliance borehole - **Fractured Aquifer**

Note: *1) mbg = metres below ground; 2) mamsl = metres above mean se level; 3) groundwater levels as per time of drilling*

Groundwater samples are collected and analysed on a quarterly basis by Yanka Laboratories, a SANAS accredited laboratory.

It should be noted that the Integrated Water Use Licence (IWUL) and the Waste Management Licence either, does not specify the groundwater limits and the chemistry results were therefore compared to the Department of Water Affairs and Forestry (DWAF, 1996) guidelines for Livestock Watering. Values that exceed the guideline limits are highlighted in red (**Table 2.10**).

The aerial distribution of manganese is presented in **Figure 2.11** and **Figure 2.12**.

Table 2.10: Groundwater quality at the Transalloys site

Date	pH	EC	TDS	Alk.	Cl	SO_4	NO_3	NH_4	F	Ca	Mg	Na	K	Fe	Mn
		(mS/m)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)
DWAF (1996)	-	-	1000	-	1500	1000	100	-	2	1000	500	2000	-	10	10
Mn Slag Dump and Fe-Cr and Mn Slimes & Return Water Dams															
BH 1															
09/03/2021	4.63	70	460	3	29	256	5.41	-	0.38	53.6	12.30	43.3	27.90	0.02	0.71
BH 2															
09/03/2021	5.91	51	301	21	5	187	0.38	-	0.44	27.2	6.43	49.0	7.31	2.58	0.70
BH 3															
09/03/2021	6.31	118	864	53	39	485	0.46	-	1.11	104.0	20.20	81.1	67.30	2.12	3.41
BH 4															
09/03/2021	6.99	17	84	73	1	5	<0.35	-	0.44	14.4	4.97	6.95	5.46	0.71	0.07
RBH 3															
09/03/2021	4.23	92	647	0	37	375	4.18	-	0.68	62.2	20.70	71.8	33.60	0.04	2.01
RGC 4															
09/03/2021	5.03	83	553	6	37	293	7.15	-	0.71	46.1	16.70	68.7	31.90	1.93	2.84
RBH 5S															
09/03/2021	6.09	79	523	32	34	272	3.50	-	0.34	44.4	18.90	68.9	31.40	0.20	2.33
RBH 5D															
09/03/2021	6.48	65	409	41	32	192	3.33	-	0.61	28.7	12.30	71.3	20.20	0.02	0.06
RGC 7S															
09/03/2021	5.95	77	519	17	37	290	0.51	-	0.51	48.1	14.60	35.5	35.50	2.40	1.63
RGC 7D															
09/03/2021	7.33	54	333	121	17	115	4.09	-	0.31	31.7	21.90	34.2	16.60	0.59	0.19
RGC 8S															
09/03/2021	7.24	160	1 159	106	30	622	0.66	-	<0.09	123.0	41.10	98.8	120.00	0.65	0.15
RGC 8D															
09/03/2021	6.68	169	1 266	77	27	692	10.60	-	<0.09	131.0	49.70	98.3	120.00	0.78	0.12

Date	pH	EC	TDS	Alk.	Cl	SO_4	NO_3	NH_4	F	Ca	Mg	Na	K	Fe	Mn
		(mS/m)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)
DWAF (1996)	-	-	1000	-	1500	1000	100	-	2	1000	500	2000	-	10	10
Raw Material Stockpile															
RBH 1C															
09/03/2021	5.91	148	962	25	94	473	6.97	-	0.12	50.3	25.5	124.0	130.0	0.08	1.74
RBH 2															
09/03/2021	5.88	4	18	5	2	3	0.82	-	0.14	1.6	0.95	2.0	1.4	<0.01	0.03
RBH 6															
09/03/2021	6.07	8	37	6	3	7	2.82	-	<0.09	3.1	1.8	4.3	1.4	0.09	0.02
Plant Complex															
RGC 3S															
09/03/2021	Dry														
RGC 3D															
09/03/2021	7.39	17	88	72	7	5	<0.35	-	0.20	14.8	5.8	6.7	4.7	0.62	0.19
Historical Raw Materials Dump															
RGC 2S															
09/03/2021	6.78	185	1 250	62	169	632	1.22	-	<0.09	101.0	55.3	182.0	61.8	0.84	1.24
RGC 2D															
09/03/2021	5.88	161	1 038	12	158	516	8.13	-	0.23	84.4	43.1	151.0	39.0	0.27	0.16
RBH 7															
09/03/2021	5.04	11	58	2	4	<0.5	8.89	-	<0.09	4.1	4.1	4.0	0.9	0.04	0.16
RBH 1A															
09/03/2021	5.60	11	56	4	4	2	7.68	-	0.11	3.9	3.5	4.9	1.2	0.04	0.16
RBH 1B															
09/03/2021	6.26	13	59	25	6	7	2.18	-	<0.09	4.2	3.1	9.0	3.9	0.02	0.14
Pollution Control Dam															
RBH 4S															
09/03/2021	6.58	174	1 135	26	123	600	3.87	-	0.26	39.0	32.8	202.0	100.0	0.07	1.52
RBH4D															
09/03/2021	4.68	229	1 607	3	150	887	9.70	-	1.09	88.3	68.2	228.0	124.0	0.02	2.45

Date	pH	EC	TDS	Alk.	Cl	SO_4	NO_3	NH_4	F	Ca	Mg	Na	K	Fe	Mn
		(mS/m)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)	(mg/ℓ)
DWAF (1996)	-	-	1000	-	1500	1000	100	-	2	1000	500	2000	-	10	10
Sewage Evaporation Ponds															
TA1S															
09/03/2021	6.31	64	357	83	54	126	1.49	-	<0.09	30.6	17.0	61.3	8.0	0.01	0.69
TA1D															
09/03/2021	6.52	66	376	150	48	99	1.99	-	1.36	37.2	22.8	53.2	10.4	0.06	2.81
TA2S															
09/03/2021	5.61	13	62	5	27	2	1.80	-	0.17	2.5	2.2	14.6	1.9	0.03	0.05
TA2D															
09/03/2021	5.52	22	116	8	41	20	1.70	-	<0.09	2.1	1.6	35.6	1.3	0.02	0.03
Highveld Steel Slimes and Return Water Dams															
RGC9S															
09/03/2021	8.32	65	342	177	86	7	0.62	-	0.12	8.3	3.2	105.0	23.3	0.54	0.04
RGC9D															
09/03/2021	7.36	77	480	79	52	215	0.51	-	0.11	50.5	8.2	79.7	21.0	0.64	0.42
Other Boreholes															
RGC1															
09/03/2021	7.14	7	35	29	2	1	0.45	-	<0.09	3.8	3.0	3.3	1.2	1.18	0.09
RGC5															
09/03/2021	6.13	13	71	29	5	2	5.35	-	0.17	5.7	4.3	3.1	3.7	2.08	0.28
RGC6															
09/03/2021	6.51	33	168	136	12	6	0.51	-	1.03	15.5	8.9	14.2	10.9	4.08	0.41

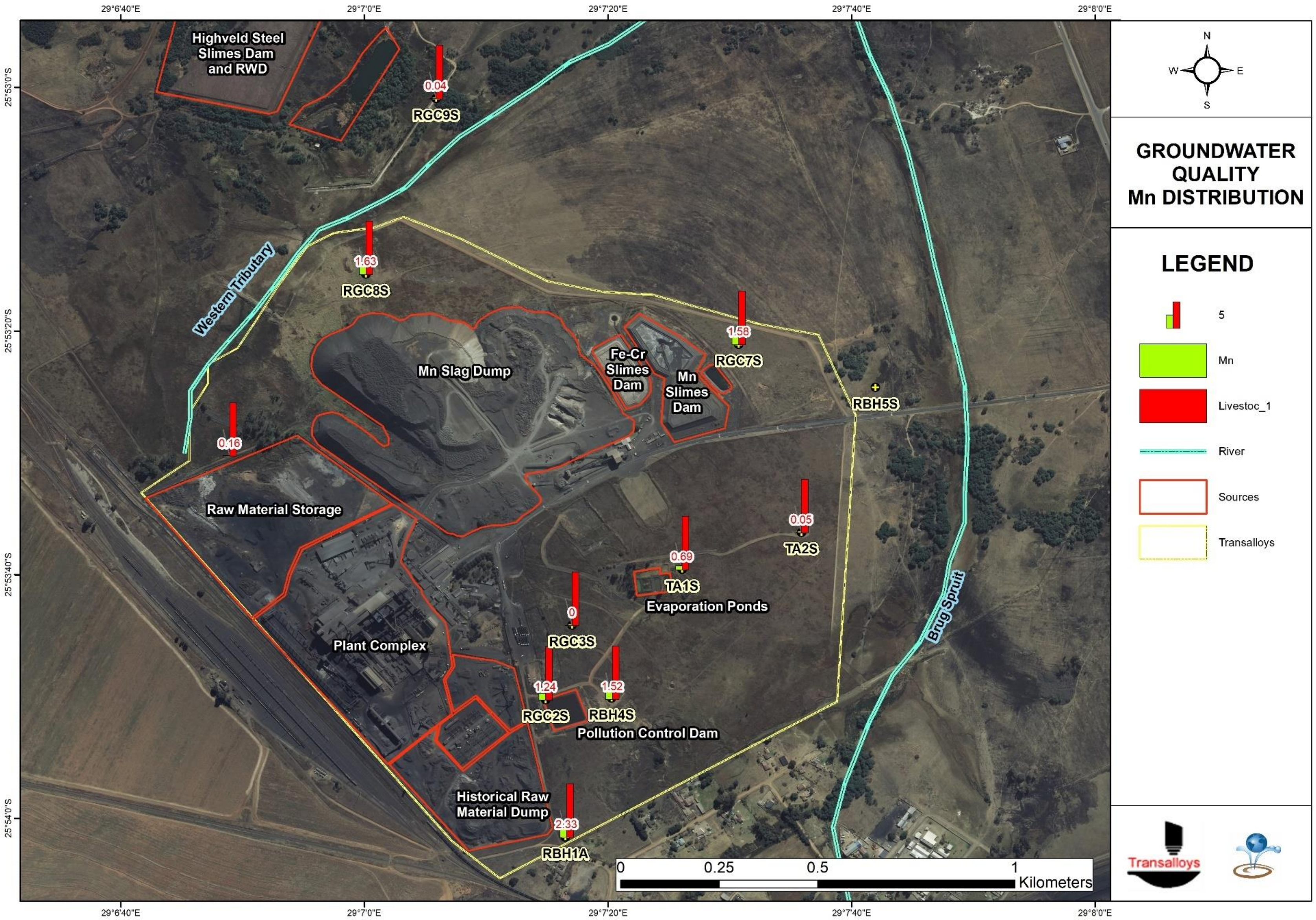


Figure 2.11: Manganese concentrations in the weathered aquifer

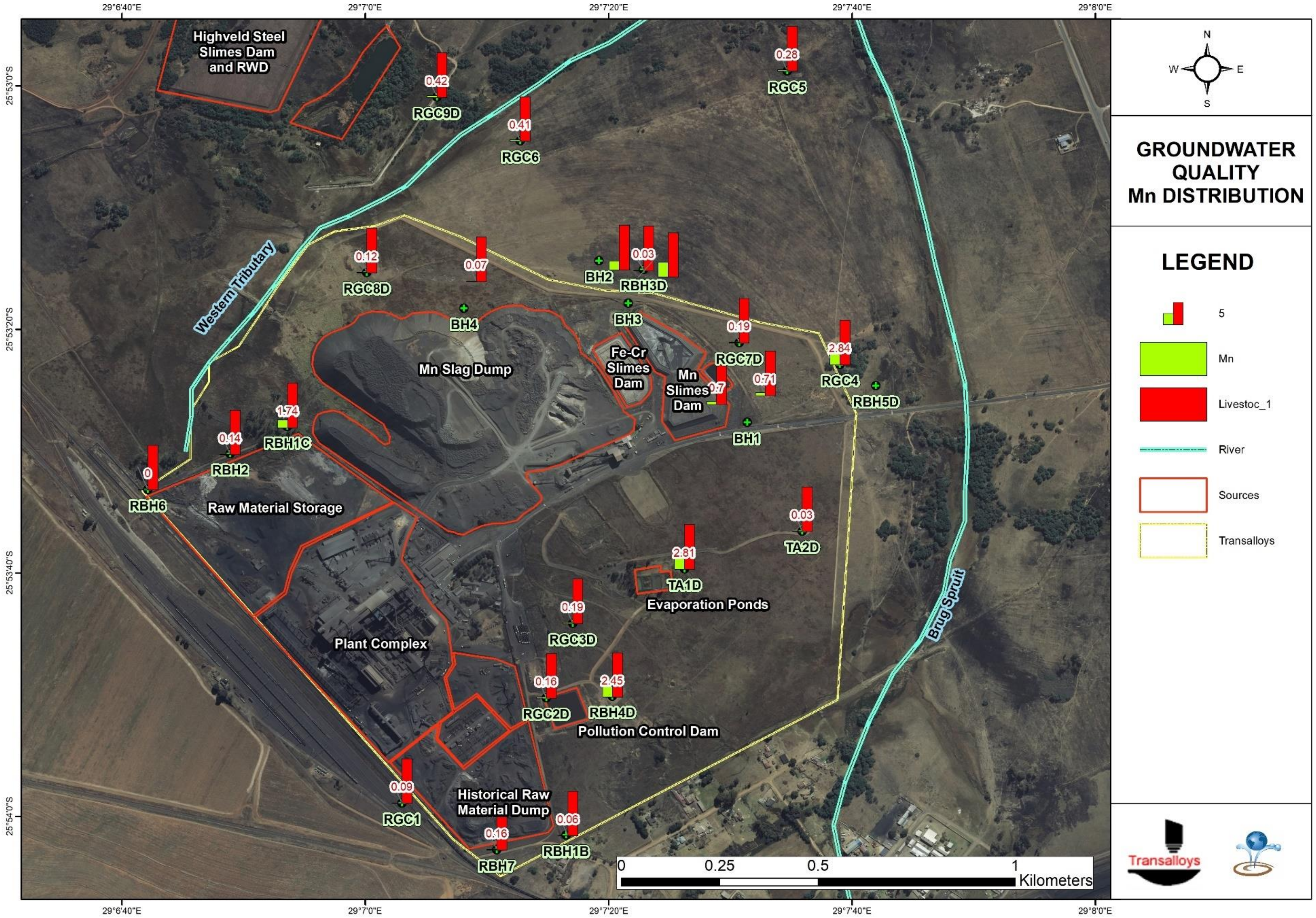
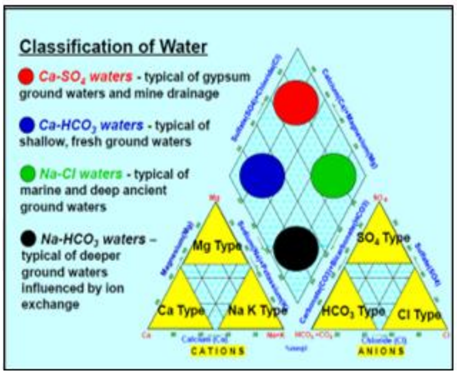


Figure 2.12: **Manganese concentrations in the fractured aquifer**

The chemical character of the water at the sampling points is best described with the aid of the Piper diagram.

The Piper diagram is one of the most commonly used techniques to interpret groundwater chemistry data.



This method proposed the plotting of cations and anions on adjacent trilinear fields with these points then being extrapolated to a central diamond field. Here the chemical character of water, in relation to its environment, could be observed and changes in the quality interpreted. The cation and anion plotting points are derived by computing the percentage equivalents for the main diagnostic cations of Ca, Mg and Na, and anions Cl, SO_4 and HCO_3.

Different waters from different environments always plot in diagnostic areas. The upper half of the diamond normally contains water of static and disordinate regimes, while the middle area normally indicates an area of dissolution and mixing. The lower triangle of this diamond shape indicates an area of dynamic and co-ordinated regimes. Sodium chloride brines normally plot on the right hand corner of the diamond shape while recently recharge water plots on the left-hand corner of the diamond plot. The top corner normally indicates water contaminated with gypsum (mine impact). In general the top half of the diamond contains static waters and other unusual waters high in Mg/Ca Cl_2 and Ca/Mg SO_4. The lower half contains those waters normally found in a dynamic basin environment. The values for mixtures of any two waters in any proportion plot along a line joining their respective points in each of these diagrams. Water therefore being invaded by an industrial effluent will plot a vector towards the analysis of the invading fluid.

The Piper diagrams for the Transalloys area is shown as **Figure 2.13**.

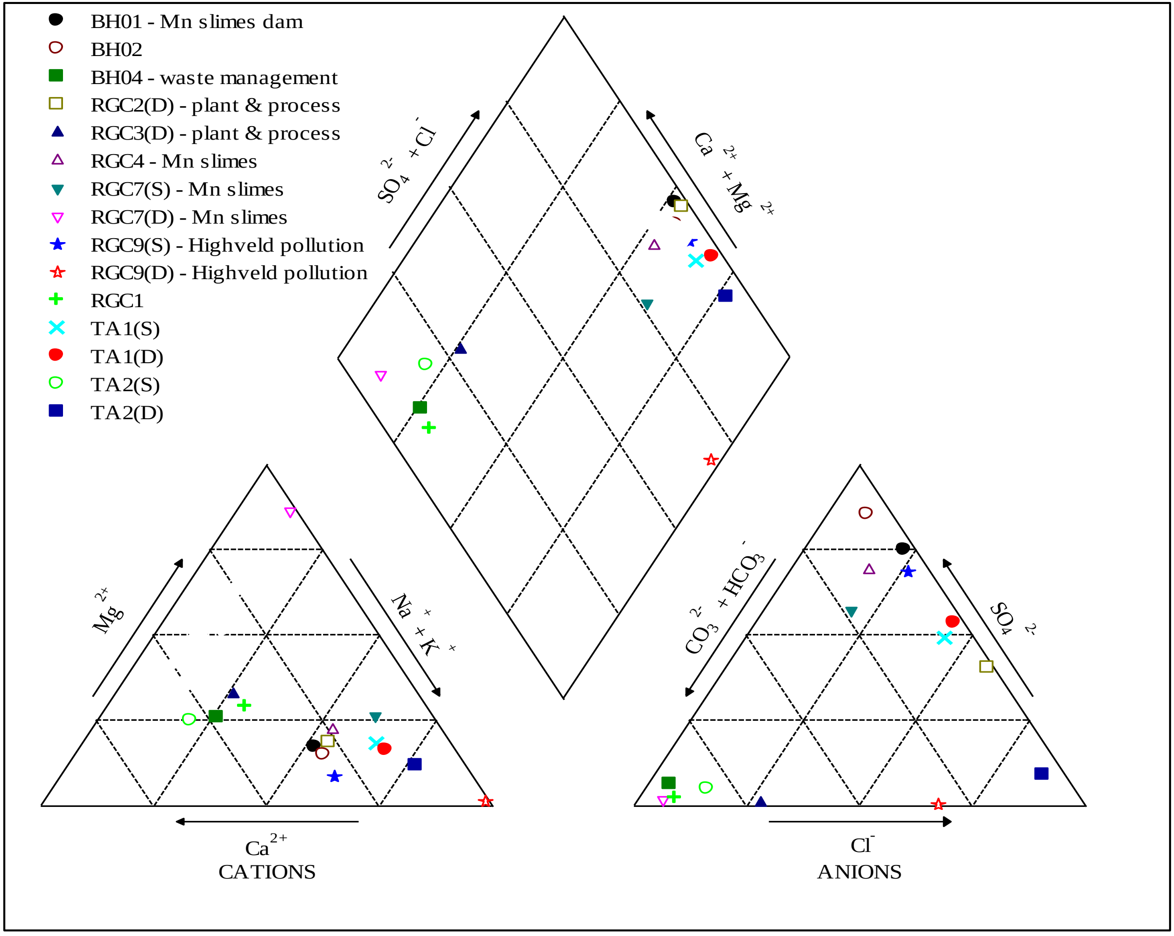


Figure 2.13: Transalloys Piper diagram

3. NUMERICAL GROUNDWATER MODELLING

3.1 Introduction

The basic steps involved in modelling can be summarised as:

- Collecting and interpreting field data: Field data are essential to understand the natural system and to specify the investigated groundwater problem. The numerical model actually develops into a site-specific groundwater model when real field parameters are assigned. The quality of the simulations depends largely on the quality of the input data.
- Calibration & validation: Model calibration and validation are required to overcome the lack of input data, but they also accommodate the simplification of the natural system in the model. In model calibration, simulated values like potentiometric surface or concentrations are compared with field measurements. The model input data are altered within ranges, until the simulated and observed values are fitted within a chosen tolerance. Input data and comparison of simulated and measured values can be altered either manually or automatically.
- Model validation is required to demonstrate that the model can be reliably used to make predictions. A common practice in validation is the comparison of the model with a data set not used in model calibration. Calibration and validation are accomplished if all known and available groundwater scenarios are reproduced by the model without varying the material properties or aquifer characteristics supplied to the model.
- Modelling scenarios: Alternative scenarios for a given area may be assessed efficiently. When applying numerical models in a predictive sense, limits exist in model application. Predictions of a relative nature are often more useful than those of an absolute nature.

3.2 Assumptions and Limitations

The following conditions typically need to be described in a model:

- Geological and geohydrological features.
- Boundary conditions of the study area (based on the geology and geohydrology);
- Initial groundwater levels of the study area.
- The processes governing groundwater flow.
- Assumptions for the selection of the most appropriate numerical code.

Field data is essential in solving the conditions listed above and developing the numerical model into a site-specific groundwater model. Specific assumptions related to the available field data include:

- The top of the aquifer is represented by the generated groundwater heads.
- The available geological / geohydrological information was used to describe the different aquifers. The available information on the geology and field tests is considered as correct.
- Many aquifer parameters have not been determined in the field and therefore have to be estimated.

In order to develop a model of an aquifer system, certain assumptions have to be made. The following assumptions were made:

- The system is initially in equilibrium and therefore in steady state, even though natural conditions have been disturbed.
- No abstraction boreholes were included in the initial model.
- The boundary conditions assigned to the model are considered correct.
- The impacts of other activities (e.g. agriculture) have not been taken into account.

It is important to note that a numerical groundwater model is a representation of the real system. It is therefore at most an approximation, and the level of accuracy depends on the quality of the data that is available. This implies that there are always errors associated with groundwater models due to uncertainty in the data and the capability of numerical methods to describe natural physical processes.

3.3 Model Set-up

In order to investigate the behaviour of aquifer systems in time and space, it is necessary to employ a mathematical model. The modelling area was selected based on a combination of topographical, geological and structural control and covers an area of approximately 24 km^2 (**Figure 3.1**).

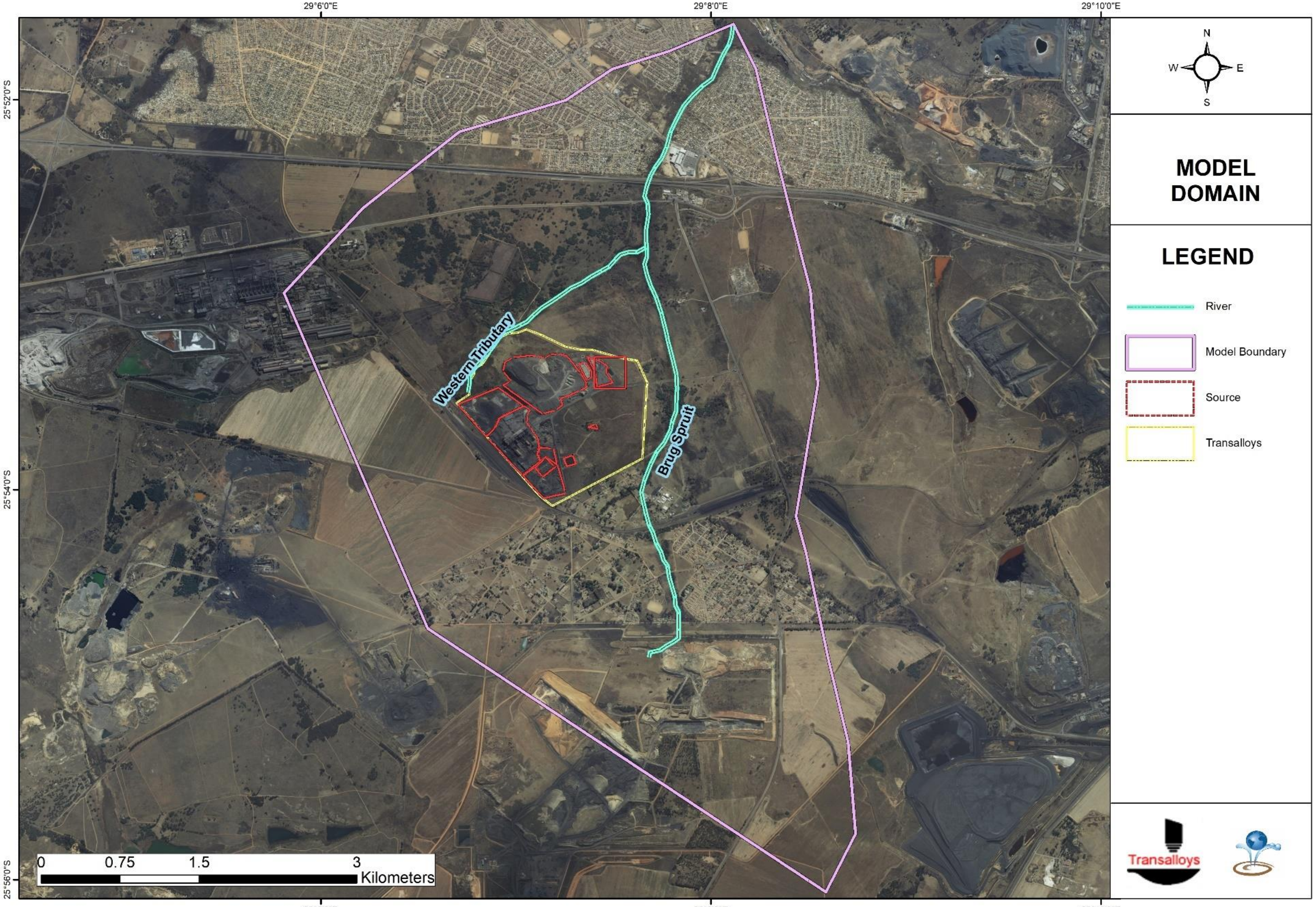


Figure 3.1: Model boundary

A two-layered aquifer model was constructed and calibrated for the Transalloys site using the finite element 3D-modelling package FEFLOW 6.2.

The model comprises 2 layers, 34 790 elements and 26 238 nodes. The total depth of the model is 59m deep. The 2 layers build into the model are:

- Layer 1 – Shallow weathered aquifer. This aquifer has an estimated average depth of 9m, but is variable throughout the model domain; and
- Layer 2 – Deeper fractured aquifer. This aquifer has an estimated depth of 50m.

The model construction is presented in **Figure 3.2**.

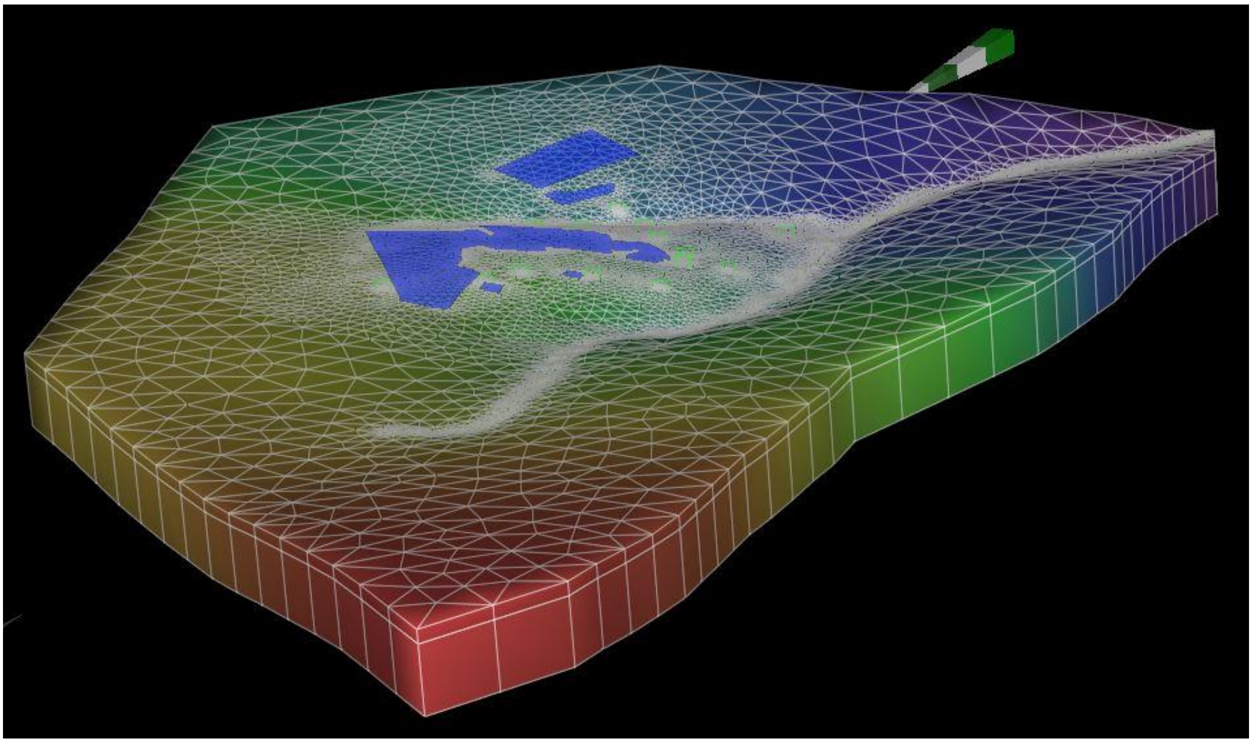


Figure 3.2: Model construction

3.4 Model Boundary Conditions

One of the first and most demanding tasks in groundwater modelling is that of identifying the model area and its boundaries. Consequently, a model boundary is the interface between the model area and the surrounding environment. Conditions on the boundaries, however, have to be specified. Boundaries occur at the edges of the model area and at locations in the model area where external influences are represented, such as rivers, wells, and leaky impoundments.

Criteria for selecting hydraulic boundary conditions are primarily topography, hydrology and geology. The topography, geology, or both, may yield boundaries such as impermeable strata or potentiometric surface controlled by surface water, or recharge/discharge areas such as inflow boundaries along mountain ranges. The flow system allows the specification of boundaries in situations where natural boundaries are a great distance away.

Boundary conditions should be specified for the entire boundary and may vary with time. At a given boundary section just one type of boundary condition can be assigned. As a simple example, it is not possible to specify groundwater flux and groundwater head at an identical boundary section. Boundaries in groundwater models can be specified as:

- Dirichlet (also known as constant head or constant concentration) boundary conditions.
- Neuman (or specified flux) boundary conditions.
- Cauchy (or a combination of Dirichlet and Neuman) boundary conditions.

Boundaries of the numerical model were chosen to reflect the geometry of the groundwater system. Since it is expected that there is a good correlation between surface topography and depth to groundwater it is possible to select surface drainage catchment watersheds as model boundaries.

3.5 Initial Conditions

Initial conditions are vital for modelling flow problems. Initial conditions should be specified for the entire area. Generally, the initial groundwater level / head distribution acts as the starting distribution for the numerical calculation. The groundwater levels shown in **Figure 2.9** were used as initial conditions for the model.

3.6 Sources and Sinks

Sources and sinks can be defined as recharge and abstraction sources in the aquifer. Sources can be precipitation and inflow from surface water and recharging boreholes. Sinks can be abstraction boreholes, springs, evapotranspiration and outflow to surface water. Initially only recharge due to precipitation was included in the model.

The steady state calibration simulations were conducted using recharge values of approximately 7mm per annum, which corresponds to 1% of the estimated annual precipitation (MAP) of 718 mm.

3.7 Aquifer Parameters

The aquifer parameters discussed in **Section 2.3.3** were initially used in the numerical model. The model is calibrated using the groundwater level elevations which are a function of the product of the saturated aquifer thickness, the hydraulic conductivity and effective aquifer recharge. Should the average aquifer thickness therefore be under/overestimated, this can be compensated for by adjustment of the hydraulic conductivity values during model calibration.

The simulated groundwater level distribution is compared to the measured head distribution and the hydraulic conductivity or recharge values can be altered until an acceptable correlation between measured and simulated heads is obtained. The calibration process was done by adjusting the model parameters for hydraulic conductivity (K) and recharge within a narrow range compatible with the test results and hydrogeological situation.

3.8 Mathematical 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 where the effect of for example the waste body is taken into account.

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]

Kx,Ky,Kz = 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]

For steady state conditions the groundwater flow Equation (1) reduces to the following equation:

$$\frac{\partial}{\partial x}(K_x\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_y\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(K_z\frac{\partial h}{\partial z})\pm W=0 \qquad (2)$$

3.8.1 Calibration of the Steady State Model

According to the conceptual model for the system the calculated head distribution ($h_{x,y,z}$) 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 recharge and evaporation values can be altered until an acceptable correspondence between measured and simulated heads is obtained.

Steady state calibration was accomplished by varying the hydraulic conductivity values within a realistic range based upon the field data and the recharge rate until a reasonable match between the measured groundwater elevations and the simulated groundwater elevations was obtained. The model was calibrated against measured groundwater levels.

The calibration objective was reached when an acceptable correlation was obtained between the observed and simulated piezometric heads. The steady state calibration results are presented in **Table 3.1** and **Figure 3.3**.

Table 3.1: Flow calibration results

Borehole ID	Observed SWL	Simulated Water level	MAE(m)	RMS(m)
	(mamsl)	(mamsl)	|(WLm-WLs)i|	(WLm-WLs)i2|
RGC1	1536.39	1536.01	0.37	0.14
RGC2d	1530.75	1529.43	1.31	1.73
RGC2s	1530.51	1529.44	1.06	1.13
RGC3d	1531.13	1526.13	5.00	24.97
RGC3s	1532.29	1529.16	3.12	9.75
RGC4	1505.19	1509.09	3.89	15.16
RGC5	1488.51	1495.14	6.63	43.93
RGC6	1494.83	1502.52	7.69	59.12
RGC7d	1510.08	1509.84	0.24	0.06
RGC7s	1509.76	1509.84	0.08	0.01
RGC8d	1516.46	1517.72	1.26	1.59
RGC8s	1516.64	1517.71	1.07	1.14
RGC9d	1490.60	1499.73	9.13	83.31
RGC9s	1506.95	1503.12	3.83	14.66
TA1D	1520.51	1518.28	2.23	4.98
TA1S	1523.55	1522.64	0.91	0.83
TA2D	1506.20	1511.99	5.79	33.58
TA2S	1507.98	1511.99	4.01	16.11
Max=	**1536.39**	**∑=**	**57.63**	**312.17**
Min=	**1488.51**	**1/n=**	**3.20**	**17.34**
Range=	**47.88**		**SQRT=**	**4.16**
			RMS% of water level range=	**0.09**

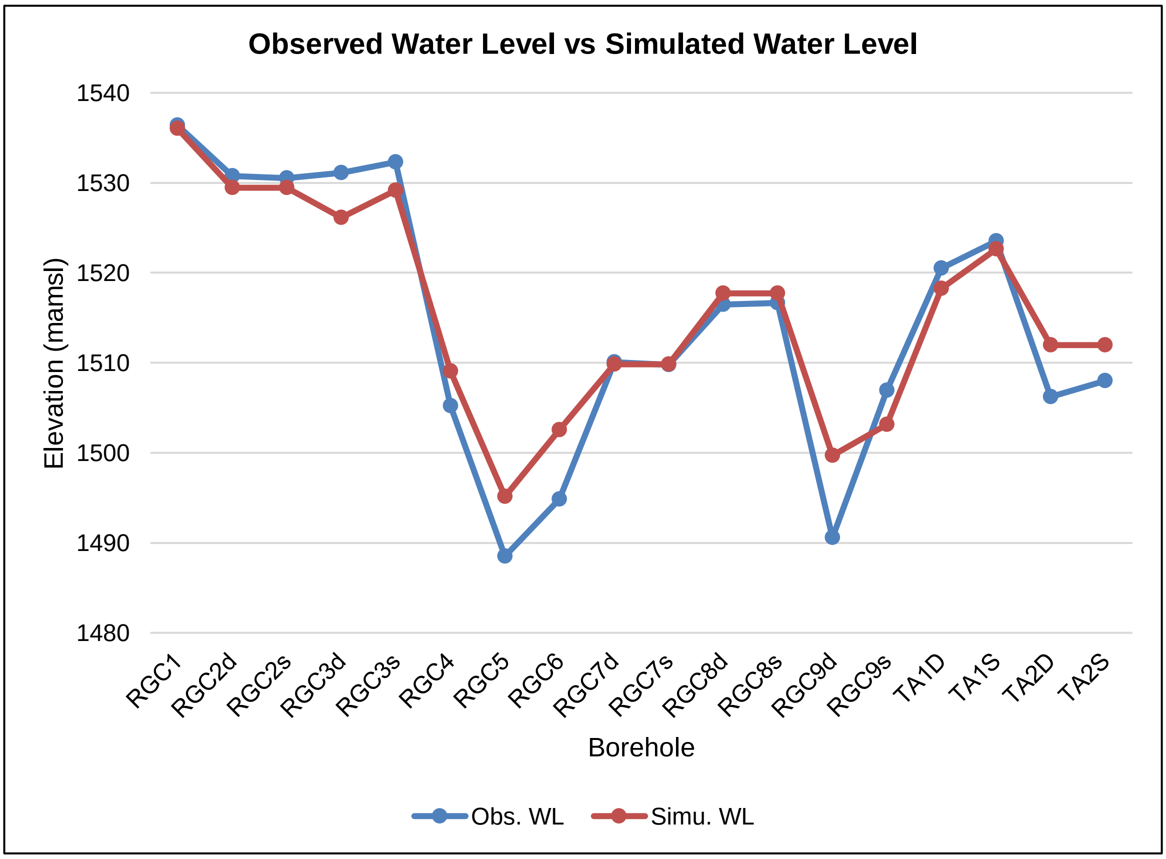


Figure 3.3: Model calibration – Groundwater level

3.9 Numerical Groundwater Mass Transport Model

Mass transport modelling in this situation refers to the simulation of water contamination or pollution due to deteriorating water quality in response to man's disturbance of the natural environment (for example waste sites). Transport through a medium is mainly controlled by the following two processes:

- 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.
- Hydrodynamic dispersion comprises two processes:
  - Mechanical dispersion is the process whereby the initially close group of labelled particles are spread in a longitudinal as well as in a transverse direction because of 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 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.

The required input into the model includes:

- Input concentrations of contaminants.
- Transmissivity values.
- Porosity values.
- Longitudinal dispersivities.
- transversal dispersivities.
- Hydraulic heads/water levels in the aquifer over time.

Transmissivities for the aquifer were specified according to the values obtained during the scenario of the steady state groundwater level calibration.

A longitudinal dispersivity value of 50 m was selected 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 5.0m was selected for this parameter during the simulations.

3.9.1 Mass Transport Model Calibration

Input concentrations in the model were specified at cells over the areas where contamination is expected.

The contaminant transport model was calibrated against the measured December 2015 TDS and manganese analysis. The results are presented in **Table 3.4** and **Figure 3.4**. It is noted that Mn does not behave conservatively in the aquifer and thus the modelling results for the Mn plume should be viewed as an approximation only.

Table 3.2: Mass transport calibration results

BHID	Obs. TDS	Simu. TDS	Obs. Mn	Simu. Mn
RGC1	45	30	0.12	0.10
RGC2d	343	290	0.06	0.09
RGC3d	95	100	0.22	0.18
RGC7d	1189	1050	0.16	0.20
RGC8d	1538	1500	1.20	1.00
RGC9d	523	545	0.01	0.05
RGC9s	766	720	1.92	1.50
TA1D	258	220	0.52	0.40
TA1S	292	220	0.36	0.50
TA2D	128	95	0.18	0.10
TA2S	68	90	0.01	0.05

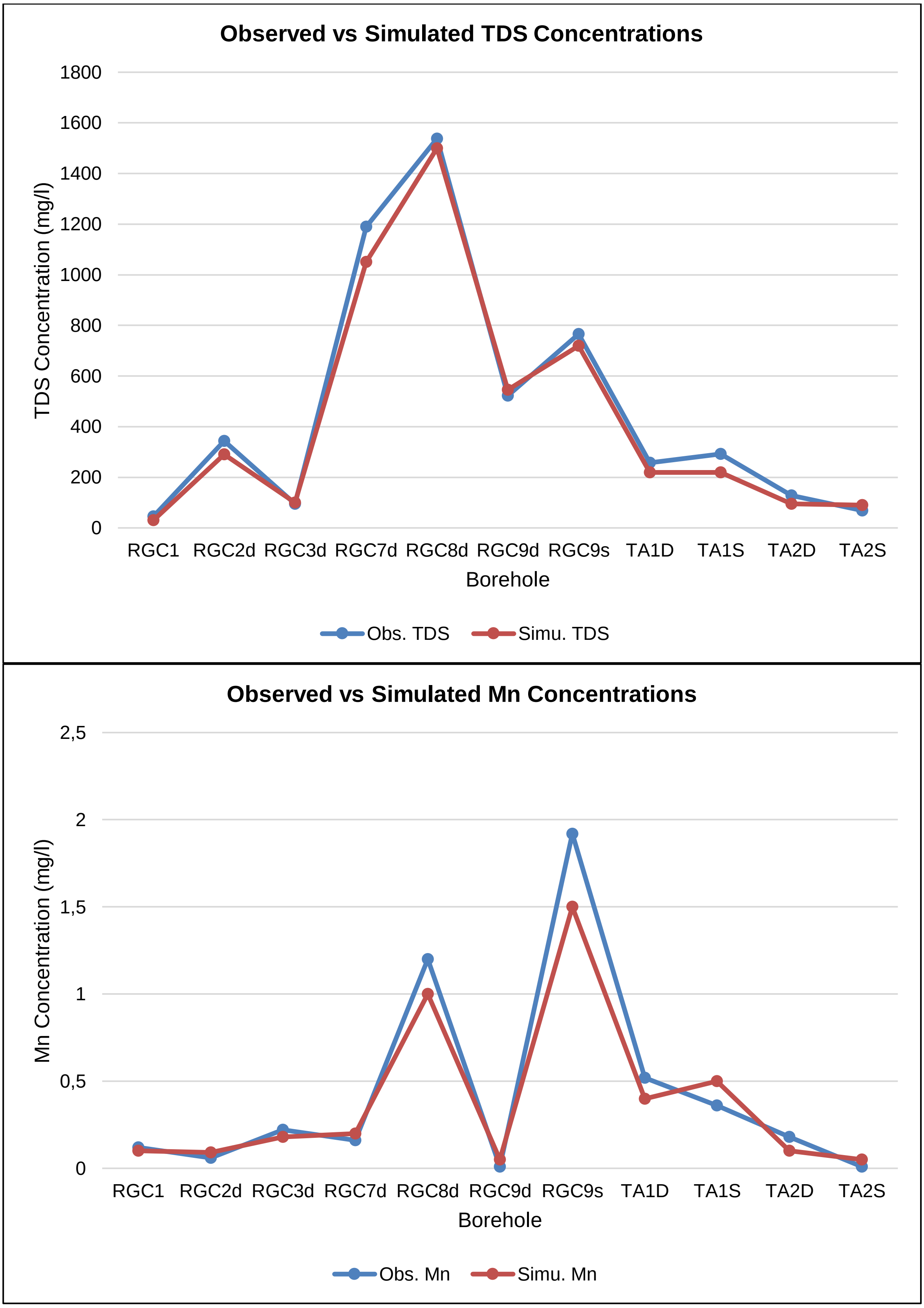


Figure 3.4: **Model calibration – Groundwater chemistry**

4. GEOHYDROLOGICAL IMPACT ASSESSMENT

4.1 Modelling Results – Current Overall Impacts

Waste material from the process is disposed at several waste facilities on the premises. Several geohydrological studies and continued monitoring has shown that these facilities have impacted on the groundwater quality, when only compared to the regional background groundwater quality. The impacts are, however, largely contained within the footprint areas of the waste body, and when compared to the Department of Water Affairs and Sanitation guidelines, the regional groundwater quality objectives are far below the recommended limits and are thus compliant.

The down-gradient receptors at Transalloys are the Brug Spruit and the Western Tributary. The surface water quality monitoring in these streams has not detected any impacts from the Transalloys waste or raw materials storage sites.

The impacted area or contaminant plume is defined as the zone in which the groundwater quality is equal to the source concentration.

The older waste facilities were established in accordance with the environmental laws at the time and as such some are not lined. These are considered the primary sources and the source concentrations are shown in **Table 4.1**.

Table 4.1: Source concentrations

Rank	Source	Concentration (mg/ℓ)	
		Mn	TDS
Unlined Facilities			
1	Manganese slag dump	15	1 600
2	Raw Material Stockpile	4.1	800
3	Historical Raw Material Dump	9.03	800
4	Manganese slimes dam	3.48	650
Lined Facilities			
5	Pollution control dam	1.28	556
6	Sewage evaporation ponds	0.38	350
7	Mn Return Water Dam	0.03	740
8	Fe-Cr slimes dam	0.68	300
9	Cr Return Water Dam	0.01	1 256

Total Dissolved Solids (TDS) and manganese (Mn) are both conservative elements that travels at the same speed as the groundwater flow. TDS provides a view of the overall groundwater quality in the region whereas the Mn specifically highlights the potential impacts of the activities and processes at Transalloys.

The current TDS concentrations in the groundwater are shown in **Figure 4.1** and the current manganese concentrations are shown in **Figure 4.2**.

With reference to these figures, it is evident that the current impacts from the waste facilities are contained within the Transalloys boundary. The down-gradient receptors, Brugspruit, Western Tributary and the township of Clewer, are not impacted in terms of the groundwater quality.

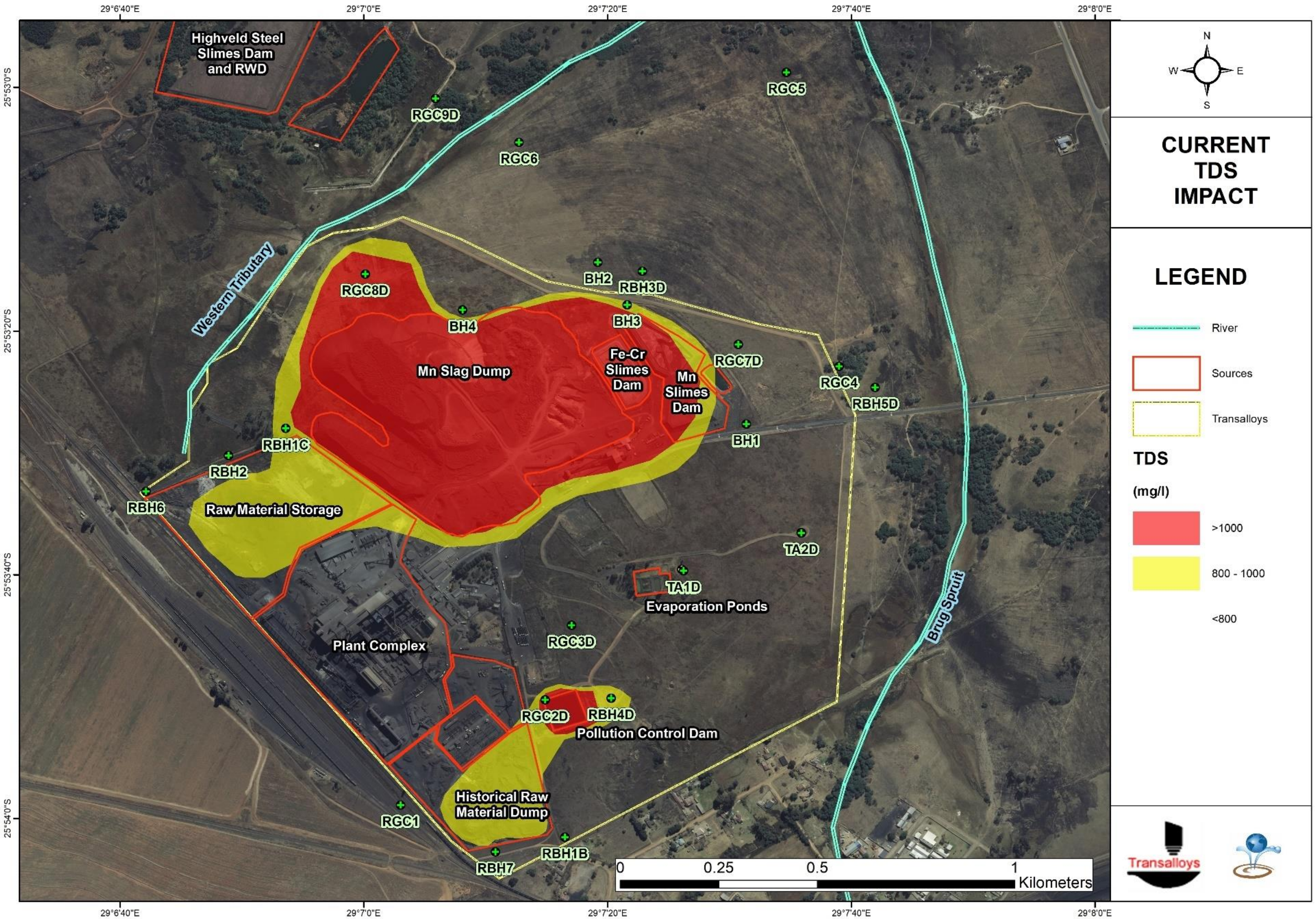


Figure 4.1: **Current extent of the TDS impact**

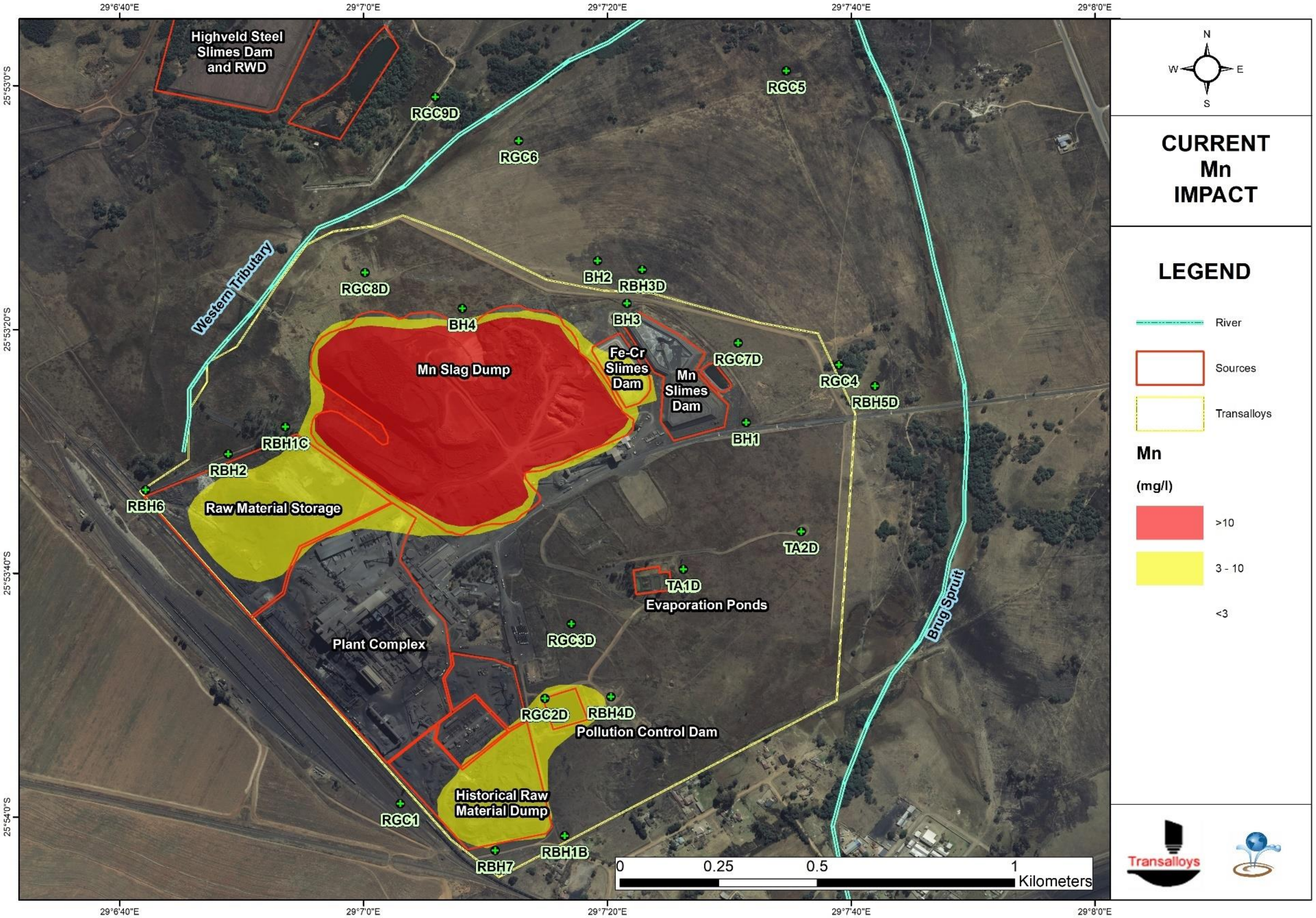


Figure 4.2: Current extent of the Mn impact

4.2 Modelling Results – Fe-Cr Slimes Dam Impact

The impacts from the surrounding waste facilities overshadows any potential impact from the FSD. These impacts were ignored, and the modelling focussed only on the FSD for this part of the assessment.

Figure 4.3 shows the FSD and the closest monitoring boreholes. **Table 4.2** compares the groundwater quality in the closest monitoring boreholes to the water in the FSD return water dam (S14) and the drain from the FSD to the FSD return water dam (S15). The latter is referred to as source water.

There is no clear indication that the FSD or its return water dam (RWD) is impacting on the groundwater. This is most likely due to both facilities being lined.

Numerical modelling of this facility is rather pointless as there is no impact on the underlying aquifers. A theoretical exercise was nevertheless done to show the potential worst-case scenario. In the model simulations it is assumed that:

- Neither the FSD nor the FSD RWD are lined.
- The facilities are isolated and none of the other waste sites are impacting on the groundwater.
- TDS is used as a conservative tracer to simulate any contaminant migration from either of these facilities.
- A source concentration of 900 mg/ℓ TDS is assumed based on the source water chemistry.

The model was run for a period of 15 years (the FSD was established in 2006) to simulate the current scenario. The FSD was then removed from the model, it is assumed that the full encapsulation of the FSD will prevent any further seepage of rainwater through the slimes. The model was then run for another 50 years to estimate the time for natural attenuation of the contaminant plume. It was found that the contaminant plume cleans-up after 20 years.

The results from the model simulations are presented in **Figure 4.4** to **Figure 4.6**. It is important to note that the simulations assumed no impact from any other source in the area. The actual concentrations measured in the boreholes may therefore not correspond with the modelling results.

Figure 4.3: **Groundwater monitoring at the Fe-Cr Slimes Dam**

Table 4.2: Source and groundwater quality

Parameter	Unit	Guidelines		S14	S15	BH02	BH03	RHH3	RGC7s	RGC7d
		DWAF (1996)	Olifants RQO	9/7/2021	9/7/2021	9/3/2021	9/3/2021	9/3/2021	9/3/2021	9/3/2021
				Source water		Groundwater				
pH		-	-	9.69	10.00	5.91	6.31	4.23	5.95	7.33
EC	(mS/m)	-	111	123	128	51	118	92	77	54
TDS	(mg/ℓ)	1 000	-	833	863	301	864	647	519	333
Alkalinity.	(mg/ℓ)	-	>60	71	87	21	53	0	17	121
Cl	(mg/ℓ)	1 500	-	42	43	5	39	37	37	17
SO_4	(mg/ℓ)	1 000	500	453	470	187	485	375	290	115
NO_3	(mg/ℓ)	100	4	0.47	0.38	0.38	0.46	4.18	0.51	4.09
F	(mg/ℓ)	2	3	1.76	1.76	0.44	1.11	0.68	0.51	0.31
Ca	(mg/ℓ)	1 000	-	129.00	133.00	27.20	10.40	62.20	48.10	31.70
Mg	(mg/ℓ)	500	-	0.91	0.13	6.43	20.20	20.70	14.60	21.90
Na	(mg/ℓ)	2 000	-	66.40	66.60	49.00	81.10	71.80	62.10	34.20
K	(mg/ℓ)	-	-	93.80	94.20	7.31	67.30	33.60	35.50	16.60
Fe	(mg/ℓ)	10	-	<0.01	<0.01	2.58	2.12	0.04	2.40	0.59
Mn	(mg/ℓ)	10	1.3	<0.01	<0.01	0.70	3.41	2.01	1.63	0.19
Cr	(mg/ℓ)			<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cr^{6+}	(mg/ℓ)			<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

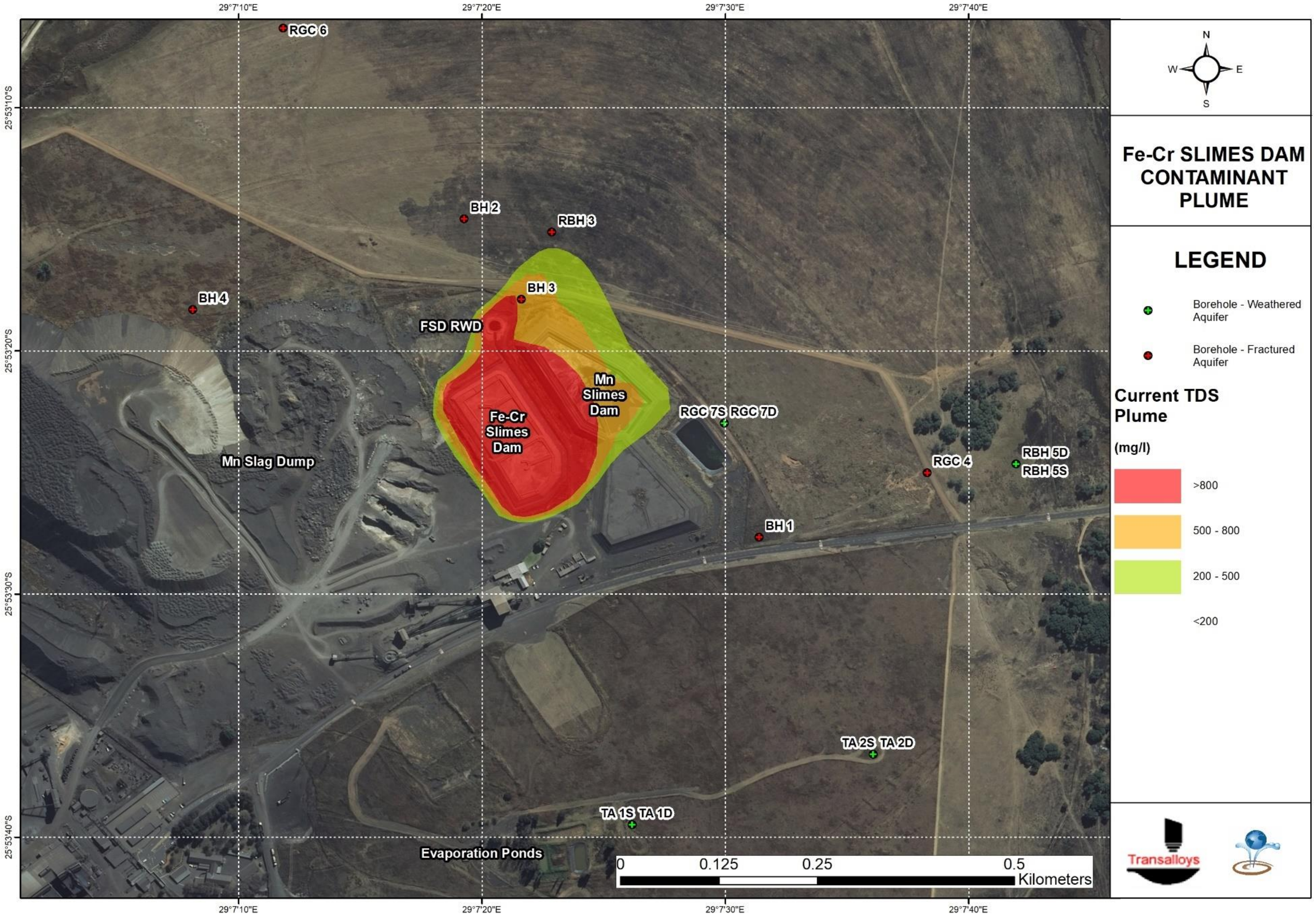


Figure 4.4: **Current impact from the Fe-Cr slimes dam (assumed unlined)**

Figure 4.5: **Impact from the Fe-Cr slimes dam (8 years after rehabilitation)**

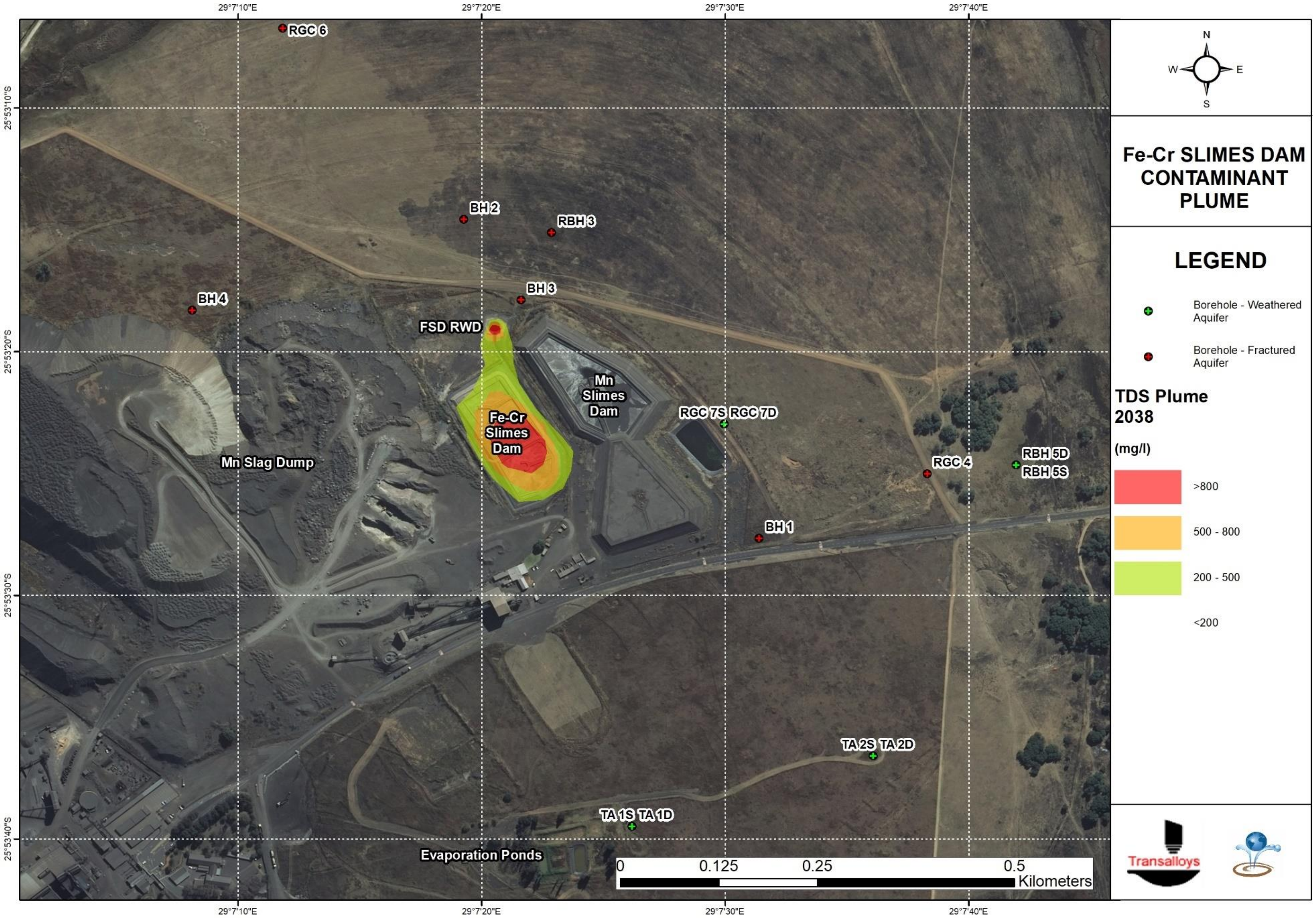


Figure 4.6: **Impact from the Fe-Cr slimes dam (18 years after rehabilitation)**

5. CONCLUSIONS AND RECOMMENDATIONS

Waste material and discard from the process is disposed at several waste facilities on site. Transalloys proposes to close the redundant Ferrochrome Slimes Dam (FSD). The FSD is a lined facility that will be closed and rehabilitated. The detailed rehabilitation plan is still being developed but it is understood that it will be fully encapsulated. From a geohydrological perspective the encapsulation of a waste body effectively removes the facility as a contaminant source as contaminated seepage into the groundwater will no longer take place.

The aim of this report was to assess the current and future geohydrological impacts from the FSD on the groundwater regime. The methodology prescribed in the BPG (DWAF, 2008) for development of the Impact Prediction, follows a risk-based approach, which is aimed at defining and understanding the three components of the risk, namely:

- The source.
- The pathway along which the risk propagates.
- The receptor that experiences the risk.

5.1 Contaminant Source

The impacts from the surrounding waste facilities overshadows any potential impact from the FSD. It is difficult to isolate the impacts from the FSD, but the groundwater quality in the closest monitoring boreholes was compared to the water in the FSD return water dam (S14) and the drain from the FSD to the FSD RWD (S15). The latter is referred to as source water and may be representative of the seepage emanating from the FSD. There is no clear indication that the FSD or its return water dam is impacting on the groundwater. This is most likely due to both facilities being lined.

A detailed waste assessment and review of the groundwater monitoring data concluded that the FSD is not considered a significant source of contamination and does not contribute significantly (if at all) to the impact on the groundwater.

5.2 Pathway

At Transalloys the geology can be divided into two distinct aquifers, namely:

- A shallow weathered aquifer, and;
- A deeper fractured aquifer.

These aquifers may or may not be hydraulically connected, dependent on the local geology and the presence of clay layers. The monitoring boreholes aimed at separating the two aquifers and in some instances borehole pairs were drilled to monitor the two aquifers separately.

The groundwater table mimics the topography and groundwater flow directions are the same as the surface water. Groundwater (and contaminant) movement through the aquifer is slow due to low aquifer parameters. This means that contaminant migration will be slow, but improvements from remedial options will also be a slow process.

5.3 Receptor

There are no groundwater users in the immediate vicinity of Transalloys and the down-gradient receptors are the Brug Spruit and the Western Tributary. The risk within these streams is primarily to livestock drinking the water.

The residential area of Clewer is close to the Transalloys boundary but is located upstream on the opposite bank of the Brug Spruit. The latter is regarded as a hydrological boundary and contamination (if any) will manifest in the stream but will not migrate beyond the stream. The groundwater in this township will therefore not be impacted by Transalloys. The surface water quality monitoring in the streams has also not detected any impacts from the Transalloys waste or raw materials storage sites.

5.4 Impact Assessment

A calibrated numerical groundwater flow and mass transport model was developed and used to simulate the migration of the plumes from the waste facilities, in this instance from the Fe-Cr Slimes Dam. Transalloys proposes to close the redundant FSD. The FSD is a lined facility that will be closed and rehabilitated. The detailed rehabilitation plan is still being developed but it is understood that it will be fully encapsulated. From a geohydrological perspective the encapsulation of a waste body effectively removes the facility as a contaminant source as contaminated seepage into the groundwater will no longer take place.

Numerical modelling of this facility is rather pointless as there is no impact on the underlying aquifers. A theoretical exercise was nevertheless done to show the potential worst-case scenario. In the model simulations it is assumed that:

- Neither the FSD nor the FSD RWD are lined.
- The facilities are isolated and none of the other waste sites are impacting on the groundwater.
- TDS is used as a conservative tracer to simulate any contaminant migration from either of these facilities.
- A source concentration of 900 mg/ℓ TDS is assumed based on the source water chemistry.

The model was run for a period of 15 years (the FSD was established in 2006) to simulate the current scenario. The FSD was then removed from the model, it is assumed that the full encapsulation of the FSD will prevent any further seepage of rainwater through the slimes. The model was then run for another 50 years to estimate the time for natural attenuation of the contaminant plume. It was found that the contaminant plume cleans-up after 20 years.

It is important to note that the simulations assumed no impact from any other source in the area. The actual concentrations measured in the boreholes may therefore not correspond with the modelling results.

5.5 Recommendations

Although the Fe-Cr Slimes Dam and return Water Dam is not believed to pose a risk to the groundwater regime, the proposed rehabilitation of this facility will further negate the risk of groundwater impacts.

Other than continued groundwater monitoring, no additional actions are recommended.

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