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Oshikoto Region

Dundee Smelter Expansion Project
Environmental Impact Assessment

Groundwater and Surface Water Study

SLR Project No.: 733.04040.00010

October 2016

Report No.: 2016-WG28

Dundee Precious Metals
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DOCUMENT INFORMATION

Title	Dundee Smelter Expansion Ground- and Surface Water Specialist Input to EIA
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Client	Dundee Precious Metals, Tsumeb
Date last printed	2017/07/04 03:06:00 PM
Date last saved	2017/01/10 06:24:00 PM
Comments	
Keywords	Impact Assessment, Smelter Expansion, Groundwater, Surface Water, Oshikoto
Project Number	733.04040.00010
Report Number	2016-WG-28
Status	Final Draft
Issue Date	October 2016

DUNDEE SMELTER EXPANSION GROUND- AND SURFACE WATER SPECIALIST INPUT TO EIA

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ACRONYMS AND ABBREVIATIONS

Below a list of acronyms and abbreviations used in this report.

Acronyms / Abbreviations	**Definition**
BH	Borehole
DPMT	Dundee Precious Metals Tsumeb
DWAF	Department of Water Affairs and Forestry
EBRD	European Bank for Reconstruction and Development
EIA	Environmental Impact Assessment
ESIA	Environmental and Social Impact Assessment
GCS	Groundwater Consulting Services
GRN	Government of the Republic of Namibia
GROWAS	Namibian National Groundwater Database, Dept. of Water Affairs and Forestry
km	Kilometre
km^2	Square kilometres
m amsl	Metres above mean sea level
m bgl	Metres below ground level
mm	Millimetres
m^3/h	Cubic metres per hour
m^3/d	Cubic metres per day
Ml/day	Million litres per day (Thousand cubic metres per day)
NASA	National Aeronautics and Space Administration
NCS	Namibia Custom Smelters
PR	Performance Requirement
QA / QC	Quality Assurance / Quality Control
RWL	Rest Water Level
SLR	SLR Environmental Consulting (Namibia) (Pty) Ltd
SRTM	Shuttle Radar Topography Mission
TGWS	Tsumeb Groundwater Study
TSF	Tailings Storage Facility

DUNDEE SMELTER EXPANSION GROUND- AND SURFACE WATER SPECIALIST INPUT TO EIA

1 INTRODUCTION

1.1 BACKGROUND

Dundee Precious Metals Tsumeb Ltd (DPMT) has applied for an Environmental Impact Assessment to be carried out for the smelter expansion in the Oshikoto Region of Namibia. The site is in the Tsumeb Townlands, on an existing site which has been operating a smelter for many years, and where various metals have been mined historically, which has had significant impacts on the environment. One of these impacts is the pollution of surface water and groundwater. In 2012 DPMT embarked on an intensive programme of upgrading the smelter operations to increase production and to improve operational efficiency and environmental performance. For this reason a new Environmental Management Plan is being developed.

SLR`s task is now to review and comment on various groundwater and surface water documentation provided by the client and produce a groundwater and surface water impact assessment for the planned smelter expansion.

The Client requested that where relevant European Bank for Reconstruction and Development (EBRD) Performance Requirements should be taken into account during this study. The main Performance Requirement with relevance to this study is EBRD Performance Requirement 3 - Resource Efficiency and Pollution Prevention and Control ("PR3"). From PR3 Section 8 (Pollution Prevention and Control), the following is noted;

"The client's environmental and social assessment process will determine the appropriate pollution prevention and control methods, technologies and practices ("techniques") to be applied to the project. The assessment will take into consideration the characteristics of the facilities and operations that are part of the project, the project's geographical location and local ambient environmental conditions. The assessment process will identify technically and financially feasible and cost-effective pollution prevention and control techniques that are best suited to avoid or minimise adverse impacts on human health and the environment. The techniques applied to the project will favour the prevention or avoidance of risks and impacts over minimisation and reduction, in line with the mitigation hierarchy approach and consistent with GIP, and will be appropriate to the nature and scale of the project's adverse impacts and issues."

The current study by SLR is an important part of this environmental assessment process, which will produce recommendations for pollution prevention and control methods as part of the mitigation measures discussed in Sections 5 and 6 of this report. .

1.2 PURPOSE AND SCOPE OF WORK

The report presents a ground- and surface water study for the proposed Tsumeb smelter expansions located at the Dundee Precious Metals site in Tsumeb.

The structure of the ground- and surface water report is as follows:

- Section 1 presents the introduction;
- In Section 2 general settings of the project area are briefly stated and the proposed development described;
- Section 3 presents the groundwater study including a description of the hydrogeological baseline conditions of the focus and surrounding areas, review and comment on various documentation provided by the client, review of groundwater monitoring network and sampling procedures, review of the latest groundwater model for the site and also recommendations for groundwater management;
- Section 4 presents the surface water study including a description of the regional and local baseline hydrology, a review of the site water balance studies, the storm water management plan and the surface water management;
- Section 5 presents the impact assessments for groundwater and surface water considering the cumulative impacts (including the planned expansions);
- Section 6 presents the summary and conclusions.

2 GENERAL SETTINGS

2.1 SITE DESCRIPTION

Figure 1 shows the smelter site location in Tsumeb and the eastern Otavi Mountainland area. The elevation at the site is approximately 1 270 m amsl, and the area slopes gently in a north-westerly direction towards the Kalahari Basin in the north.

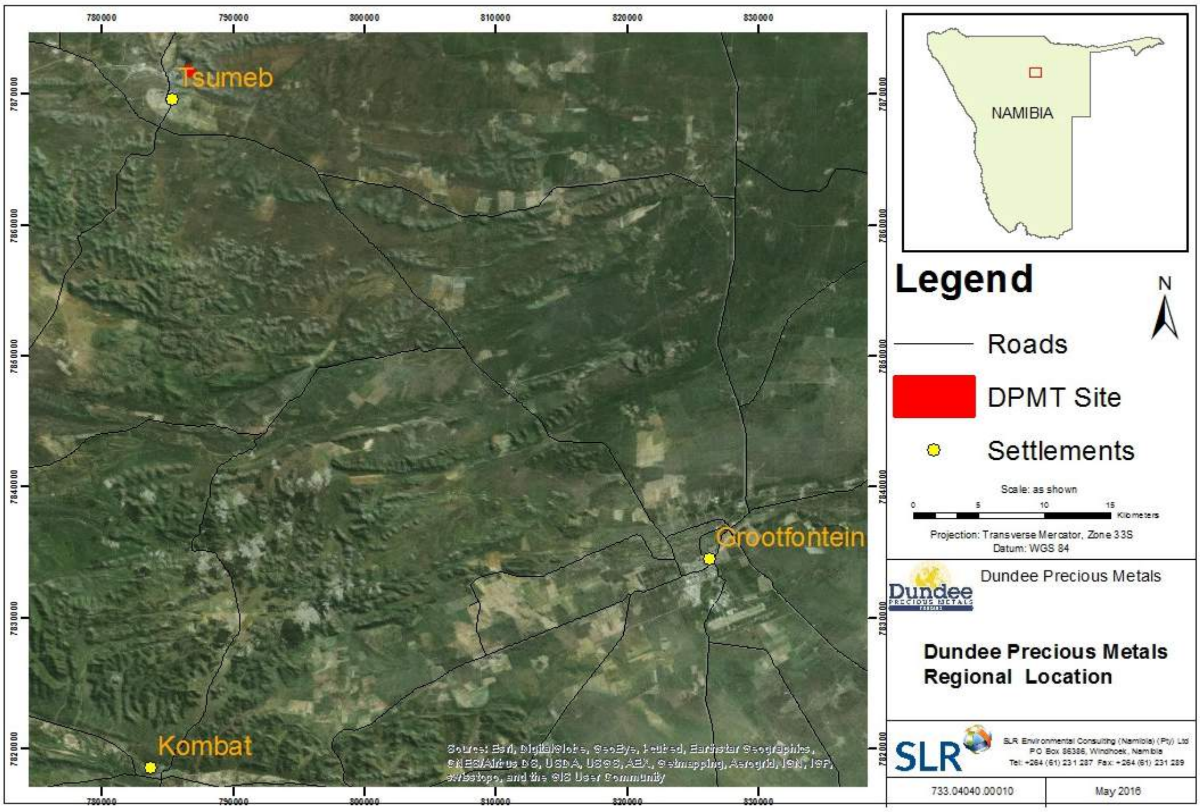

FIGURE 1: LOCATION OF SITE IN THE EASTERN OTAVI MOUNTAINLAND AREA

Figure 2 shows the site with elevation data from SRTM (Shuttle Radar Topography Mission) supplied by the NASA. From this it can be seen that the smelter site is located within a valley running in a south-east to north-west direction just to the north of the main Tsumeb town.

Figure 3 shows some of the main processing infrastructure around the site, along with the main drainage lines through the site.

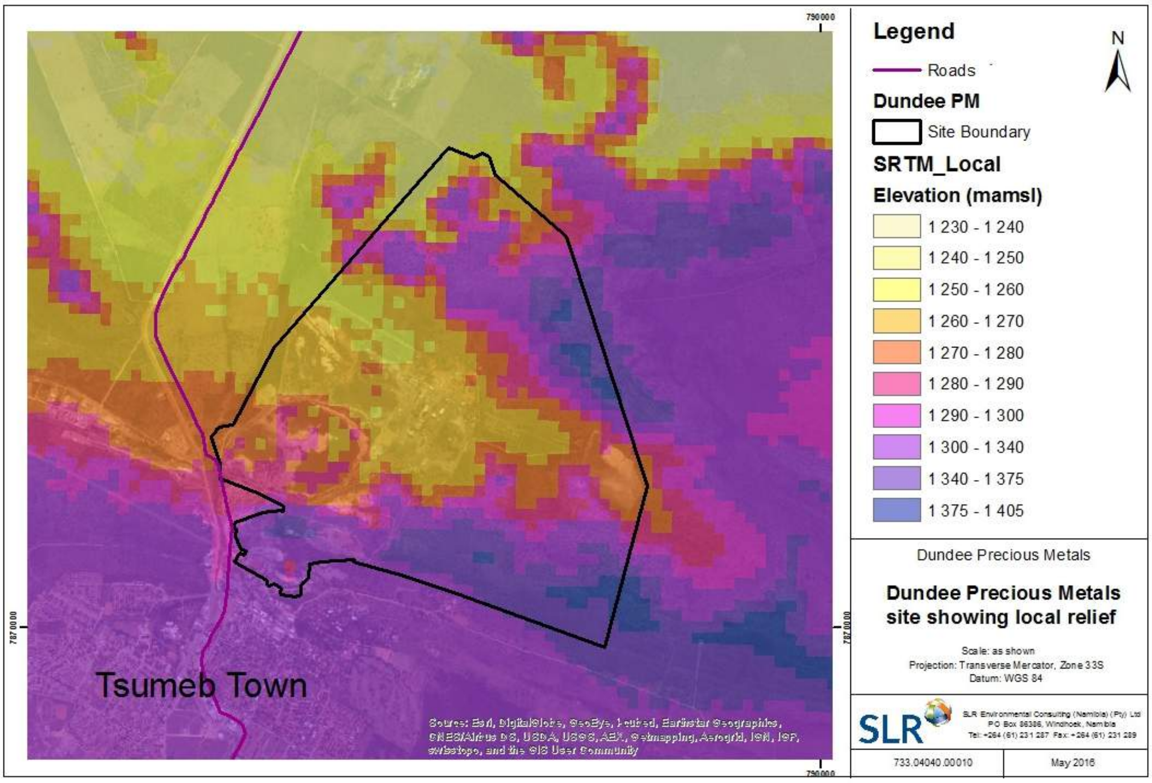

FIGURE 2: GENERAL LAYOUT OF SITE SHOWING RELIEF

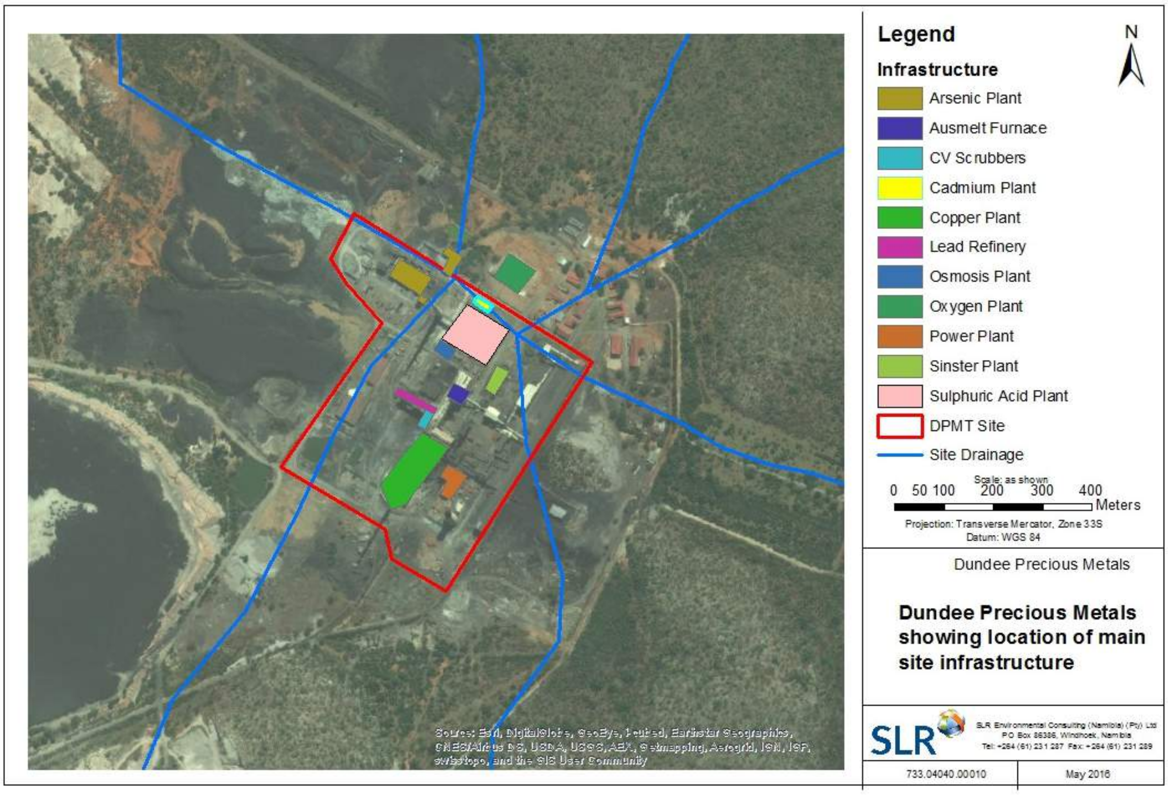

FIGURE 3: GENERAL LAYOUT OF SITE SHOWING INFRASTRUCTURE

2.2 CLIMATE

The ATLAS OF NAMIBIA, 2002 shows the study area to have an annual average temperature of 20 to 22°C, with an average maximum of 32 to 34°C during the hottest month (December) and an average minimum of 6 to 8°C during the coldest month (July), with an average of 1 to 5 frost days per year.

2.2.1 RAINFALL

The nearest long and reliable rainfall record to the smelter site is from Tsumeb Meteorological Station, which is less than 1 km from the site.

Tsumeb has a Meteorological Office rainfall record of approximately 90 years length (1913/14 to present with some lost data, see Appendix 2), which provides a fairly accurate long-term average. Rainfall data has been analysed for the hydrological year, which runs from 1st October to 30th September, hence years are shown as 1913/14, being data for October 1913 through to September 1914. The average monthly rainfall values are shown in Table 1 and Figure 4 which shows that the majority of rainfall (88 %) falls between November and March. The mean annual precipitation (MAP) is 503 mm and there are two months of average rainfall greater than 100 mm (January and February), with the highest monthly rainfall being 370.6 mm recorded in February 1944. The highest annual rainfall was 1,006 mm recorded in 1943/44 and there have been ten years when the annual rainfall was over 700 mm. Annual rainfall data recorded at Tsumeb is shown graphically in Figure 5.

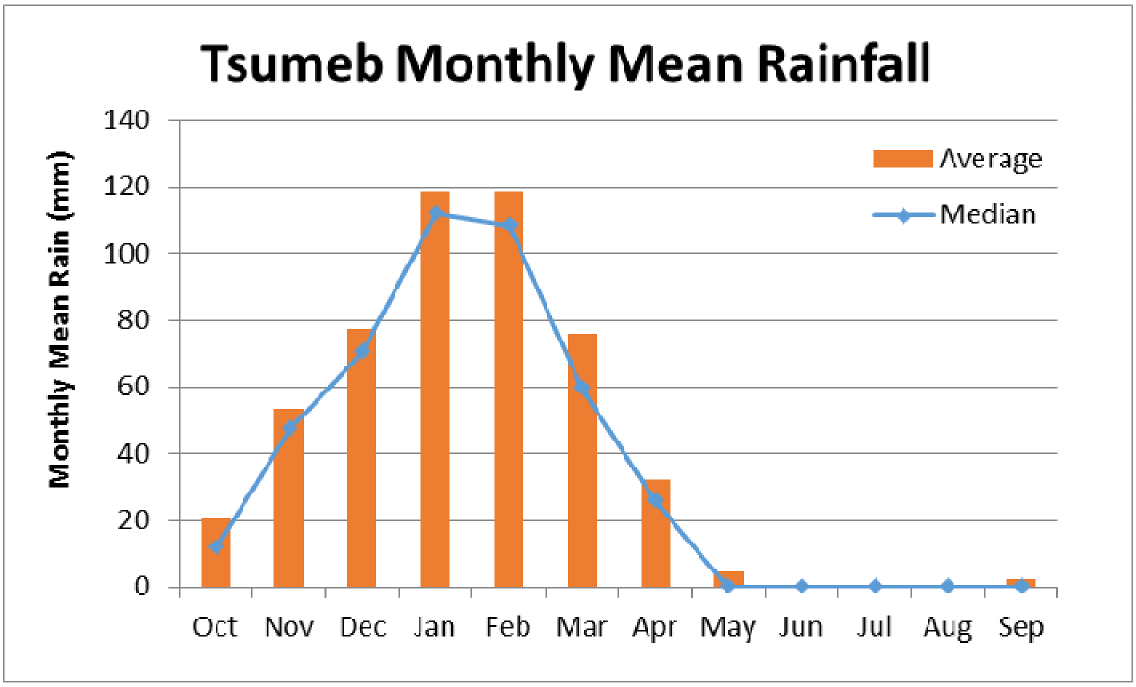

FIGURE 4: TSUMEB MONTHLY MEAN RAINFALL DISTRIBUTION

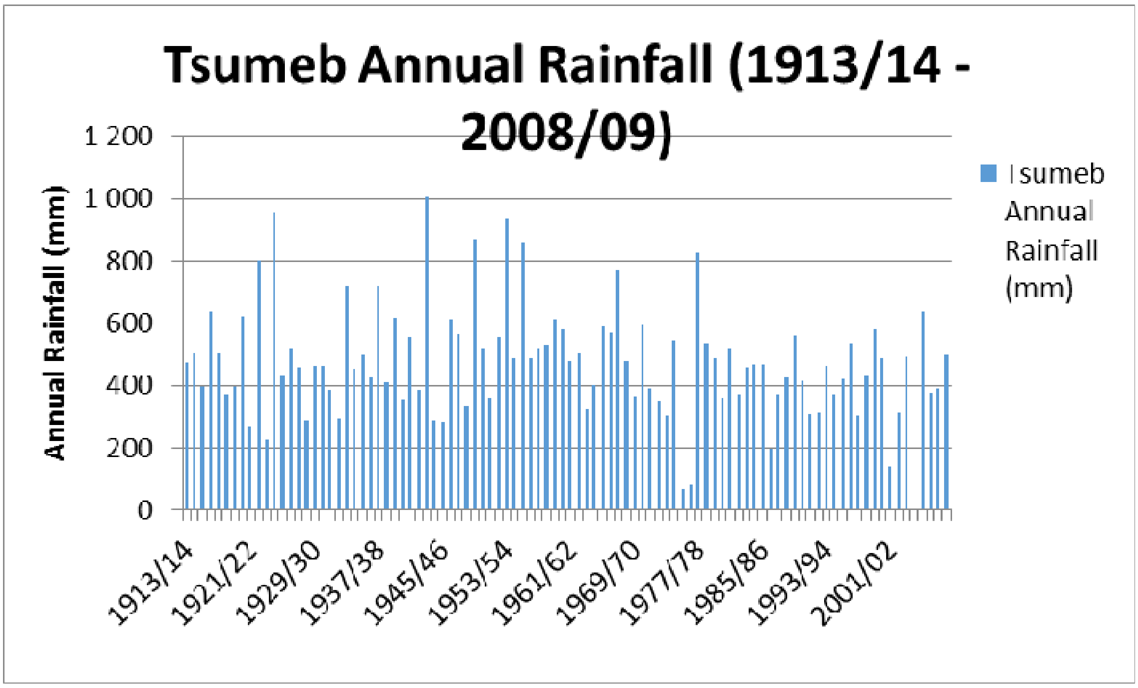

FIGURE 5: TSUMEB ANNUAL RAINFALL

The rainfall data (1913/14 to 2008/09) for the Tsumeb Met Office rain gauge was analysed for exceedance using the Cunane Plotting Equation Pt = (M-0.4) / (N+0.2) where ;

PT = Probability of Exceedance,

N = Total Number of Observations,

M = Ranked Number of Observed Value,

with the resulting rainfall exceedance for the station shown in Figure 6.

Rainfall seasons with lost data in the months between November and March were highlighted and excluded from the analysis, with the exception of 1933/34 which was a significantly wet year and is included to allow storm water calculations to be more conservative.

From this it can be seen that in Tsumeb there is an 80 % probability that the annual rainfall will be approximately 370 mm, a 50 % probability that the annual rainfall will be 480 mm and a 20% probability that the annual rainfall will be approximately 590 mm.

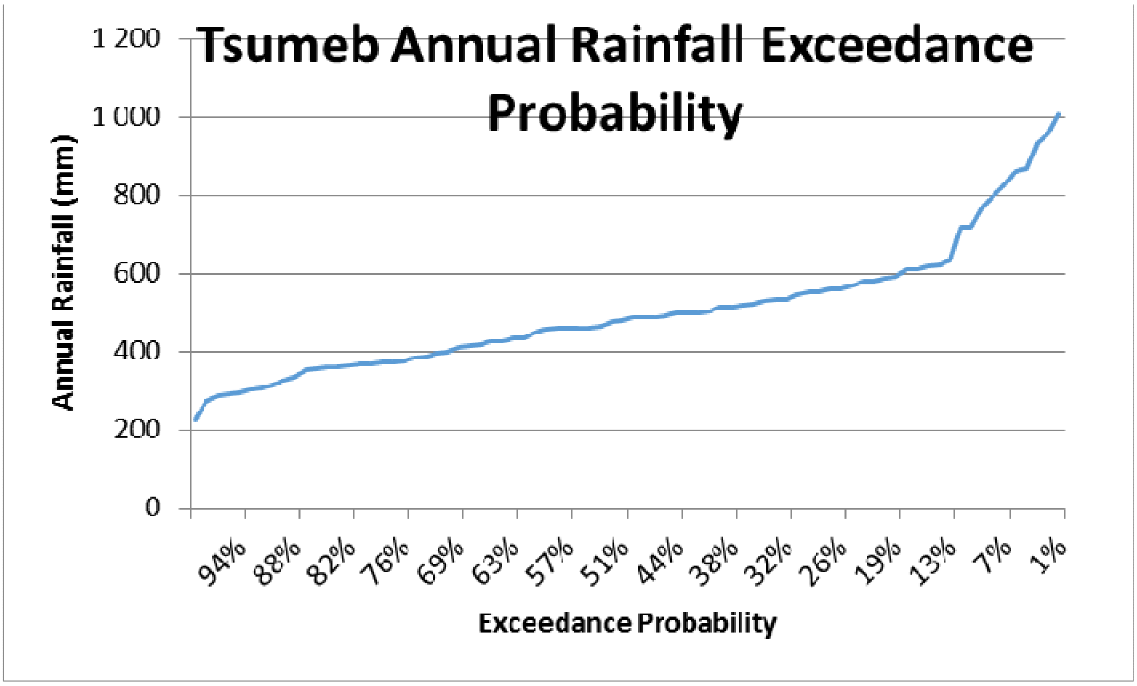

FIGURE 6: TSUMEB MET. OFFICE SITE RAINFALL EXCEEDANCE

Rainfall is generally from storms producing short cloud-bursts of low to high intensity, but as the site is located in the karst area where infiltration is relatively high, reduced surface runoff volumes should be expected.

2.2.2 EVAPORATION

Calculated from Namibian Meteorological Office (Met. Office) Class-A evaporation pan data, the following evaporation data was taken from the Department of Water Affairs Evaporation Map Report (1988).

The A-pan evaporation values for Tsumeb were then converted to open water values (evaporation from a Class-A evaporation pan is higher than from an open body of water) to compile an estimated evaporation distribution for the Tsumeb area. The estimated open water evaporation values are shown in Table 1 and in Figure 7.

TABLE 1: TSUMEB AREA MONTHLY RAINFALL AND EVAPORATION DATA

Tsumeb Mean Annual Evaporation	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Monthly Percentage	11.9	11.2	11.8	10.7	8.0	7.3	6.2	5.5	4.9	5.4	7.3	9.8	100
A-Pan Evaporation (mm)	249.2	234.5	247.1	224.1	167.5	152.9	129.8	115.2	102.6	113.1	152.9	205.2	2 094
Open Water Evaporation (mm)	174	164	173	179	134	122	104	92	82	90	122	164	1 602
Tsumeb Mean Monthly Rain (mm)	20.4	53.4	77.3	118.3	118.6	76.2	32.1	4.5	0.4	0.0	0.1	2.5	504

As can be seen from these figures the monthly evaporation for all months is higher than the rainfall, indicating that the Tsumeb area is a water negative area, meaning that there is an overall deficit in the available water, especially during the months from April to November, when there is little or no rainfall. However, from Figure 7 it can be seen that in January and February the mean monthly rainfall and evaporation are much closer, suggesting that the area becomes more of a water neutral area, where rainfall nearly matches evaporation.

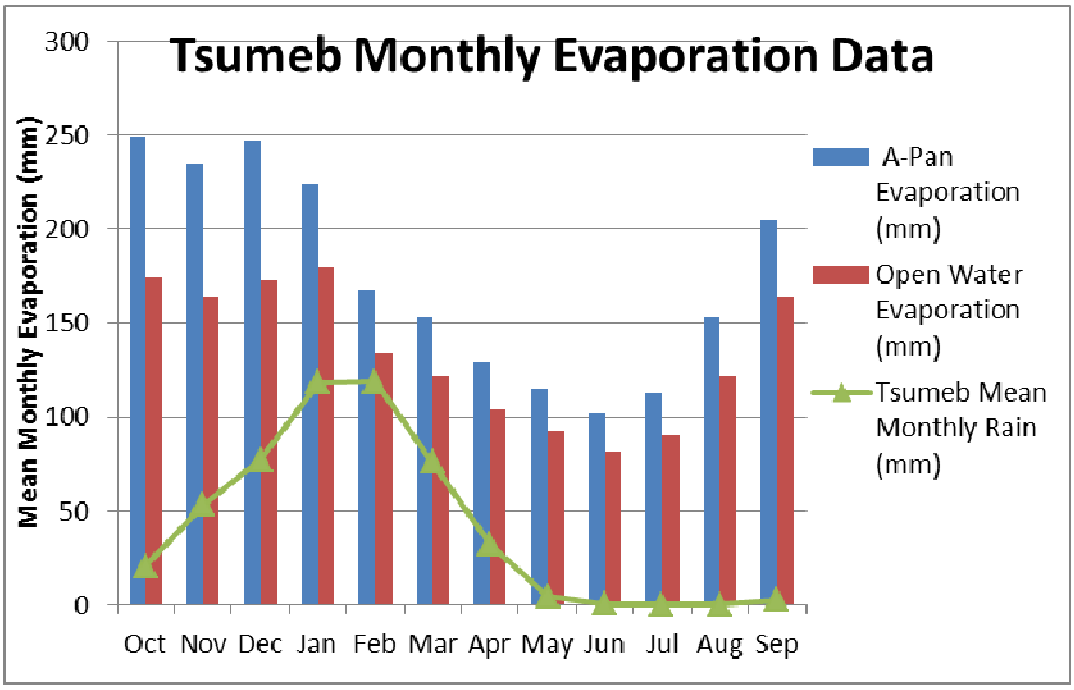

FIGURE 7: MEAN MONTHLY EVAPORATION AND RAINFALL FOR TSUMEB AREA

2.3 SOIL

Data on dominant soils was sourced from the Atlas of Namibia (Mendelsohn 2002), i.e. the information presented is not based on a field survey.

Dominant soils prevailing in the Tsumeb area rock outcrops (representing the karst) with a band of Chromic Luvisols running approximately east to west through the area. Chromic refers to soils with bright colours and luvisols are a soil unit which only occurs (in Namibia) in two small areas west of Grootfontein, which have good water holding capacity and are well drained with a porous and aerated structure. Luvisols typically comprise an accumulation of clay that has settled some depth below the surface.

2.4 GEOLOGY

The period 900-950Ma was marked by extensive continental fragmentation with geosynclinals deposition in a major Late Proterozoic – Early Paleozoic tectono-thermal event referred as Pan-African event (Master, 1991). Downward flexing of the craton margins produced extensive intra-cratonic foreland basins (Thomas & al, 1993). The late Proterozoic to Early Palaeozoic Damara belt forms part of the Pan-African mobile system belt, which surrounds and bisects the African continent (Martin 1983, Miller 1983a),

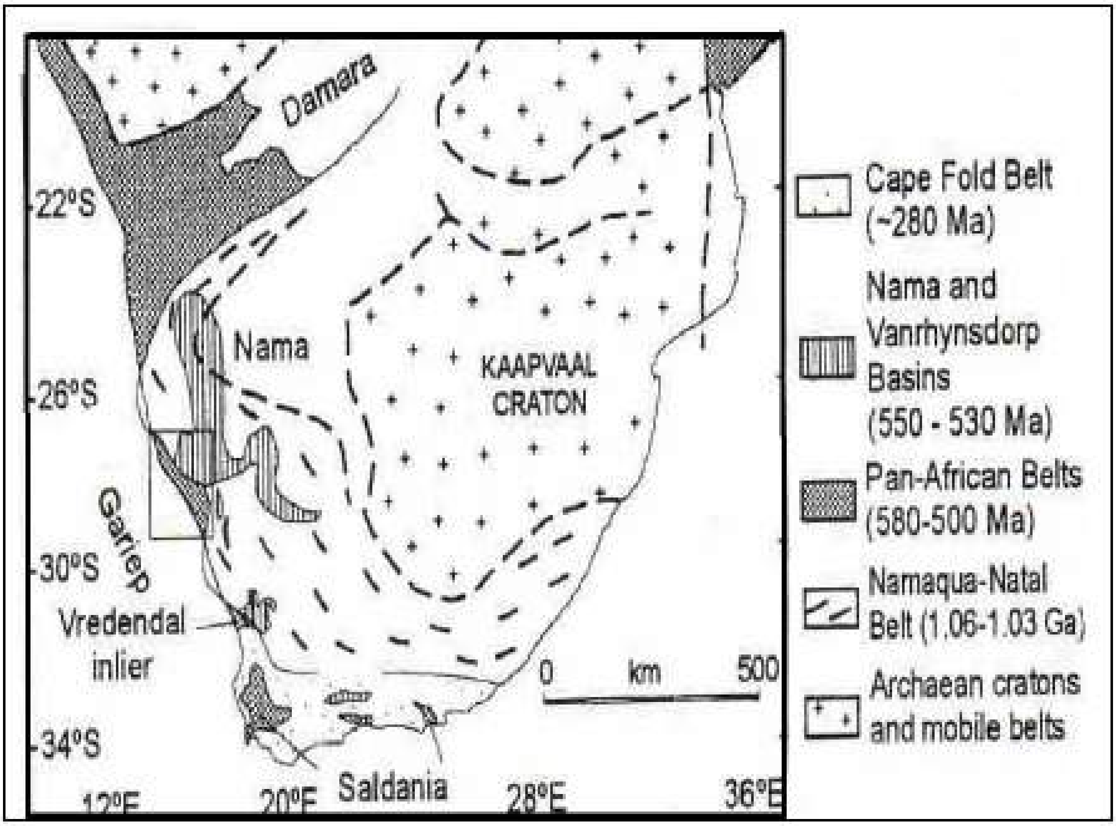

Figure 2.2: Location of the Pan African Belts, Archaean Cratons, the Namaqua – Natal Metamorphic Province and the Cape Fold Belt (modified after Miller 1983a).

FIGURE 8: LOCATION OF THE PAN AFRICAN BELTS (MODIFIED AFTER MILLER 1983A)

The NE-trending Pan-African Damara Belt is 400 km wide and is located between the Congo and the Kalahari Cratons in the South West region of Southern Africa (Figure 8).

The Damara Supergroup consists of a north east trending intracontinental arm and a north south trending coastal arm with a present outcrop width in Namibia of 150 km. The triple junction between the two arms is located off the coast near Swakopmund (Miller, 1983c). Evolution of the belt involves a complex history which includes rifting, spreading, convergence and collision of Kalahari and Congo Cratons. In addition to this, deformation, metamorphism and magmatism accompanied the collision. Subsequently the belt underwent episodes of continental rifting, ocean floor spreading, glaciation, subduction, collision and metamorphism over a time span of about 250Ma (Figure 9).

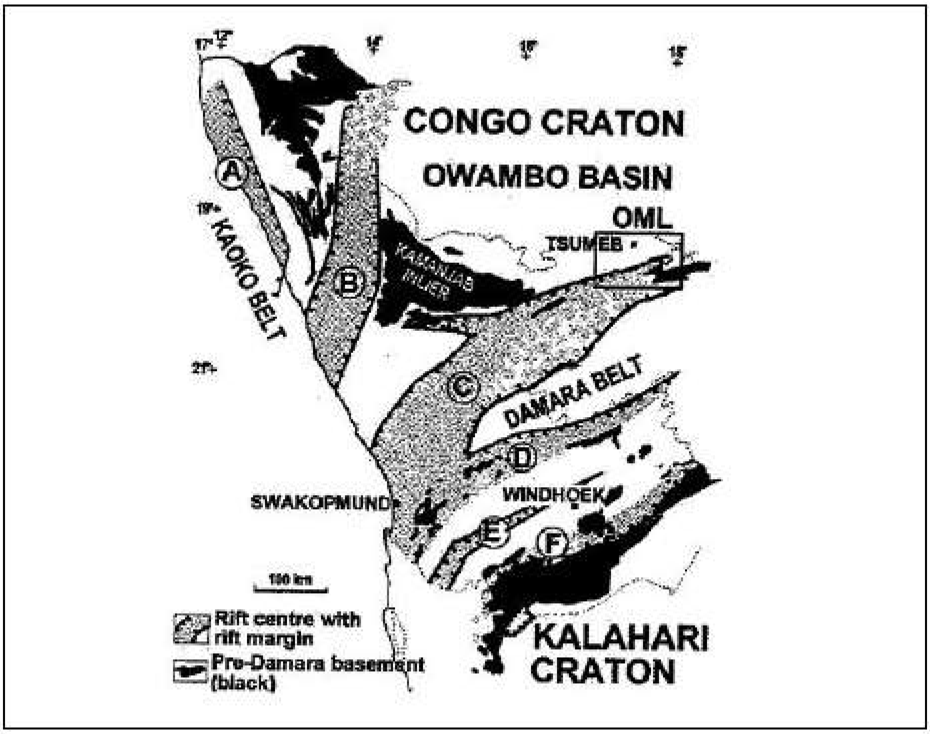

Figure 2.4: Location of the Otavi Mountain Land (OML), the Owambo Basin and the presumed location of the continental rift structures during the rifting stage of the Damara and Kaoko Belts (from Porada 1989). A = Kaoko Rift, B =Sesfontein, C = Northern Rift, D = Central Rift, E = Khomas Rift, F =Southern Rift. Note that the southern and eastern limits of the Owambo Basin are defined by the Northern boundaries of the Kamanjab inlier and the Northern Rift (C) as well as the eastern margin of the Sesfontein Rift (B). *Modified after Kamona and Gunzel, (2006)*

FIGURE 9: LOCATION OF THE OTAVI MOUNTAINLAND (OML)

2.4.1 STRATIGRAPHY

Rocks of the Damara Supergroup were deposited on an Archean granite-gneiss Basement exposed in the northern and southern zones, and in the inlier in the centre of the belt (Jacob & Kroner, 1977). The Basement complex crops out in several major inliers along the northern and southern margins of the Damara province, as well as numerous small inliers in the central parts. A stratigraphic column for the Otavi Mountainland (OML) is shown in detail in Table 2, and Figure 10 depicts the regional geology.

TABLE 2: GEOLOGY AND STRATIGRAPHY OF THE AREA

(Stratigraphic Column for the Otavi Mountainland, revised after Hoffmann and Prave (2008))

SUPER GROUP	GROUP	SUB GROUP	Age, Ma	FORMATION	LITHOLOGY	ZONE
Deposits	MULDEN		550	Tschudi	Arkose, feldspathic sandstone, grit conglomerate	
				Kombat	Phyllite, interbedded with lenticular dolostone	
	Disconformity		570			
Kombat (Cu – Pb – Ag)	Kombat Ore Bodies		760?	Hüttenberg	Thin Bedded Light dolostone with algal markers and chert beds, prominent pisolite-oolite chert beds at the top	T8
				Hüttenberg	Thin Bedded Dark Dolomites with Phyllite, black oolitic chert, anhydrite horizons silicified reef/bioherm (Tschudi area)	T7
				Hüttenberg	Thin Bedded Limestone and Shale	T7
Tsumeb (Cu – Pb – Zn – Ag)	OTAVI	Tsumeb		Hüttenberg	Bedded Light Dolomite and Chert (Algal), stromatolites ("Tuten" marker beds in Tsumeb)	T6
				Elandshoek	Massive and Bedded Light Dolomite	T5
				Elandshoek	Massive Light Dolomite, with bedded dolostone	T4
				Maieberg	Thin Bedded Dolomite	T3
				Maieberg	Thin Bedded Limestone, Quartzite	T2
				Maieberg	Bedded Dolomite, Thin-bedded Limestone, greenish-grey shale	T2
				Maieberg	Thin-bedded Limestone and Shale	T2
				Maieberg	Localized Tillite and Limestone	T2
Abenab (Pb – Zn – V)				Keilberg	Fine grained laminated to massive pale pink dolostone	
		Disconformity		Ghaub	Massive carbonate clast dominated diamictite	T1
				Ghaub	Medium to thin bedded diamictite with dropsotnes	T1
DAMARA		Abenab		Auros	Bedded Dolomite (Quartz Clusters) Massive Dolomite (Algal – Columnar) Bedded Limestone and Shale Massive Dolomite (Algal – Columnar) Bedded Limestone and Shale Massive Dolomite (Algal – Cryptozoon) Bedded Limestone and Shale Massive Dolomite (Jasperoid) Bedded Limestone and Shale	
Berg Aukas (Pb – Zn – V)				Gruis	Pink and light pinkish grey fine grained, micritic dolostone and chert, oolite and stromatolite at top, interbedded with shale locally.	
	Disconformity		830	Gauss	Very Light grey, pinkish grey and buff enterolithic dolomicrite dessication structures and microbial, stromatolite, micrite Very light to medium grey and buff massive dolostone with vuggy/colloform texture local stromatolite and oolite Grey to light grey, buff and pink medium and thin bedded and laminated dolosotne	
	NOSIB		840	Berg Aukas	Dark grey microbial laminated/stromatolitic dolostone, local chert laminated rhythmite dolostone	
		Unconformity		Varianto(Chuos)	Diamictite, pebbly grit, iron formation	
			1000	Nabis	Shale, Phyllite Conglomerate, Arkose, Quartzite	
BASEMENT COMPLEX			1800		Diabase, Granite and Gneiss, Diorite, Gabbro, Serpentinite	

The Nosib Group unconformably overlies the Basement Complex. It consists of the Nabis, Chuos, Berg Aukas and Gauss formations. The environment of deposition progressively developed from predominantly fluvial to marine when finer grained shales were deposited (Kamona & Gunzel, 2006).

The Otavi Group consists of Abenab and the Tsumeb subgroups which are unconformably overlying the Nosib Group and the Basement Complex (Hedberg, 1979). The latest, the

Tsumeb Subgroup, is subdivided into 8 litho-zones (T1 to T8) from the clastic Ghaub Formation to the carbonate dominant Maieberg, Elandshoek as well as the Hüttenberg Formations.

The **Ghaub Formation**, referred to as T1, is a glacio-marine tillite with lenses of dolomite and schist.

The **Maieberg Formation** is a platform slope, deep water deposit and overlies the Ghaub Formation. The lower Maieberg Formation (T2) consists of slump brecciated and laminated carbonate and argillaceous sediments. The upper Maieberg Formation (T3) comprises bedded and finely laminated carbonates.

The **Elandshoek Formation** conformably overlies the Maieberg Formation. It covers most of the northern limb of the Otavi Valley north of Kombat Mine. The lower Elandshoek Formation (T4) comprises of massive dolomite and is responsible for the rugged geomorphologic terrain of the northern limb of the Otavi Valley. The brecciation is generally intensive and therefore T4 is regarded as an important aquifer (Van der Merwe, 1986). The upper Elandshoek Formation (T5) is fairly thin and not easily distinguishable from T4.

The **Hüttenberg Formation** marks the change from the deep sea environment observed in the Elandshoek Formation to shallow lagoon shelves. It consists of a grey bedded basal dolomite, stromatolite rich (T6), overlain by two upper units, a massive dark and bedded dolomite with chert and with phyllite (T7) and T8 is marked by pisolite and oolite.

The **Mulden Group** is characterised by the **Kombat Formation** in the southern part of the OML, which consists of a siliciclastic molasses (poorly graded phyllite, arkose, argillite and siltstone) deposited syn-tectonically during the early stage of the Damara Orogeny, and the **Tschudi Formation** (Arkose and feldspathic sandstone) in the northern part of the OML, and is separated from the Tsumeb Subgroup by an angular disconformity.

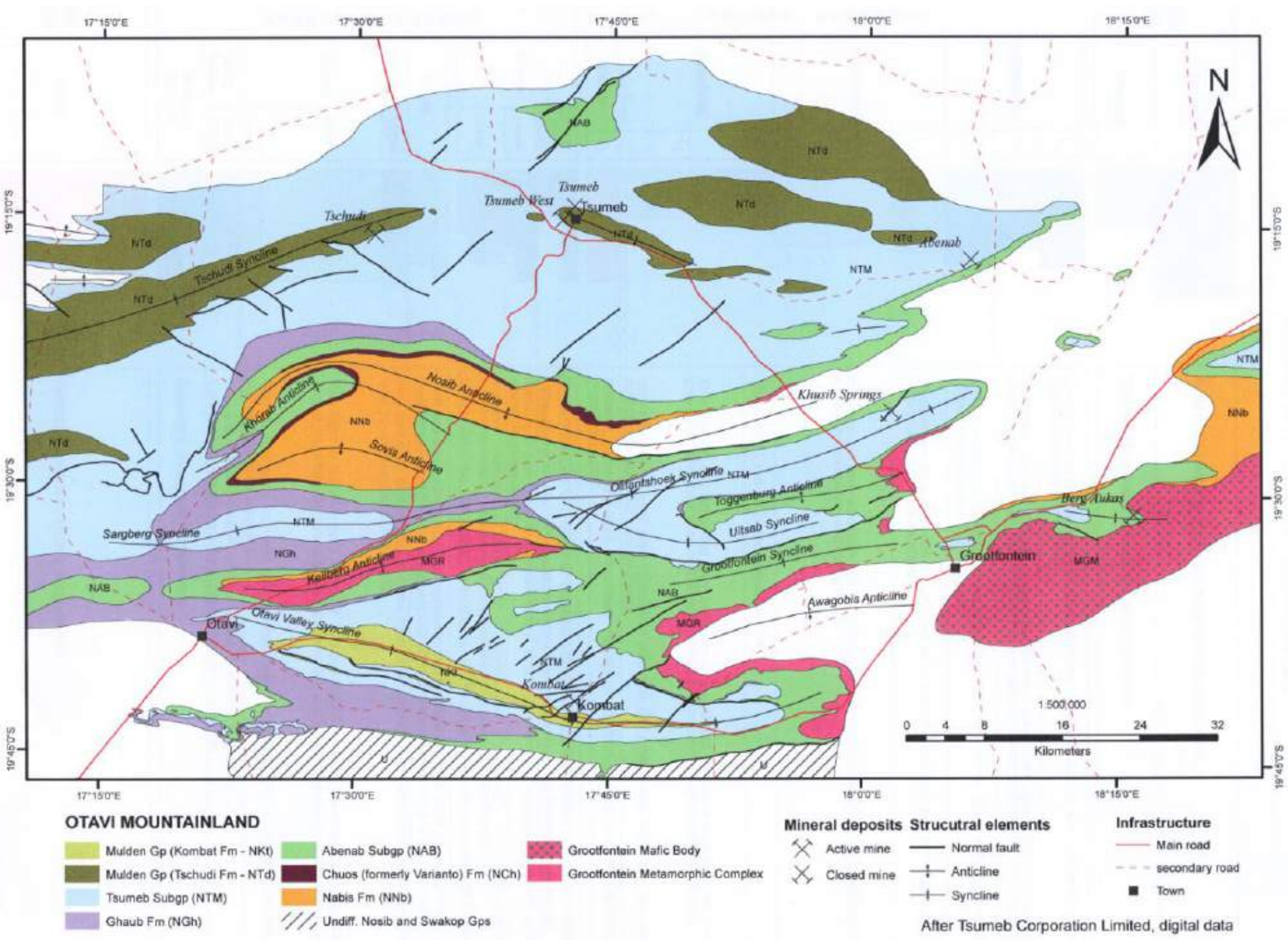

FIGURE 10: PRE-KALAHARI GEOLOGY OF THE OTAVI MOUNTAIN LAND (AFTER TCL, DIGITAL DATA)

2.4.2 DPMT HYDROGEOLOGICAL SETTINGS.

The town of Tsumeb lies on the northern edge of the OML and is characterised by the sandstones of the Tschudi Formation (Mulden Group) and extends in an east-west direction. The Tsumeb Smelter is located on the T5 (Elandshoek Formation) and T6 (Hüttenberg Formation) lithozones, in an ESE-WNW sloping valley formed as part of an anticlinal structure. The groundwater is expected to move in fold axes, pressure relief joints, faults or on lithological contact zones (Figure 11).

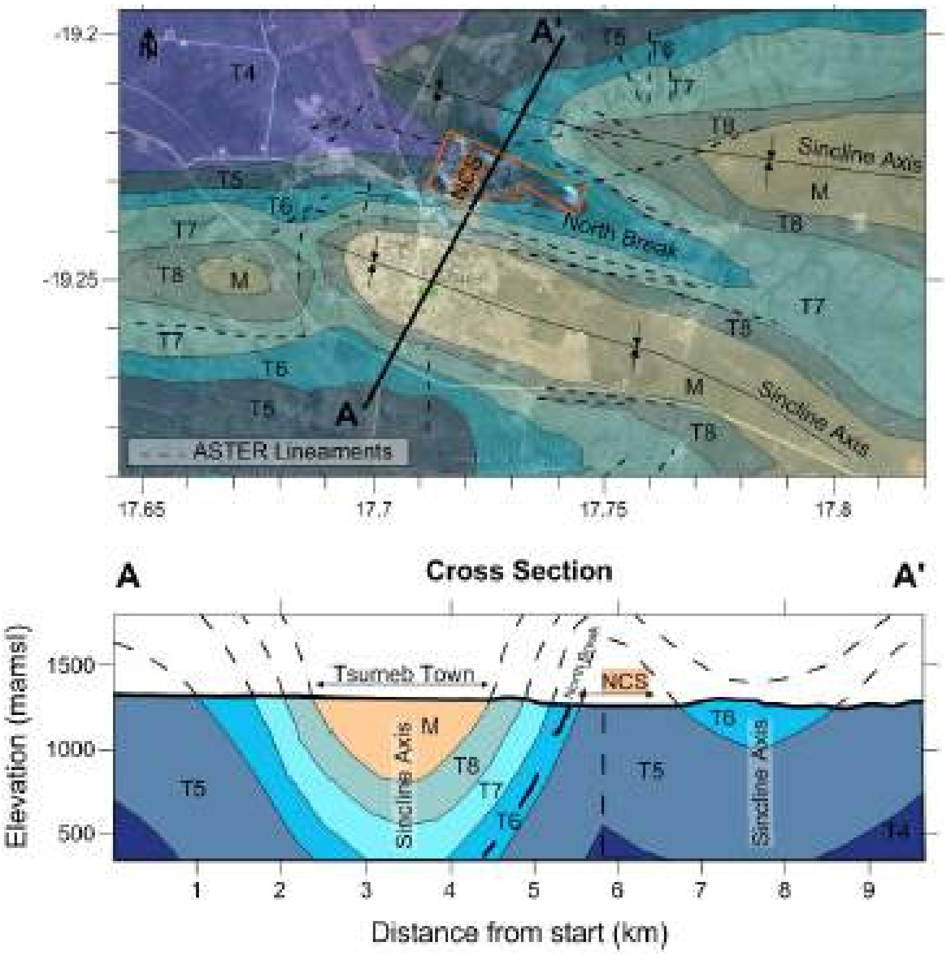

FIGURE 11: LOCAL GEOLOGY AROUND THE DPMT SITE, WITH SW-NE CROSS SECTION (GCS: 2013)

The groundwater generally flows in a northerly direction within the highly permeable (k=1.08 m/d, (GCS 2013)) dolomites of the Hüttenberg Formation (Figure 13). The dolomitic hills consist of the T7 (Hüttenberg Formation) litho-zone, highly karstified and considered as an aquifer (Figure 13) as well as the T6 litho-zone (Figure 14) whereby giving only one K (Hydraulic conductivity) value might not be ideal; as a matter of fact the hills are a recharge zone for the groundwater.

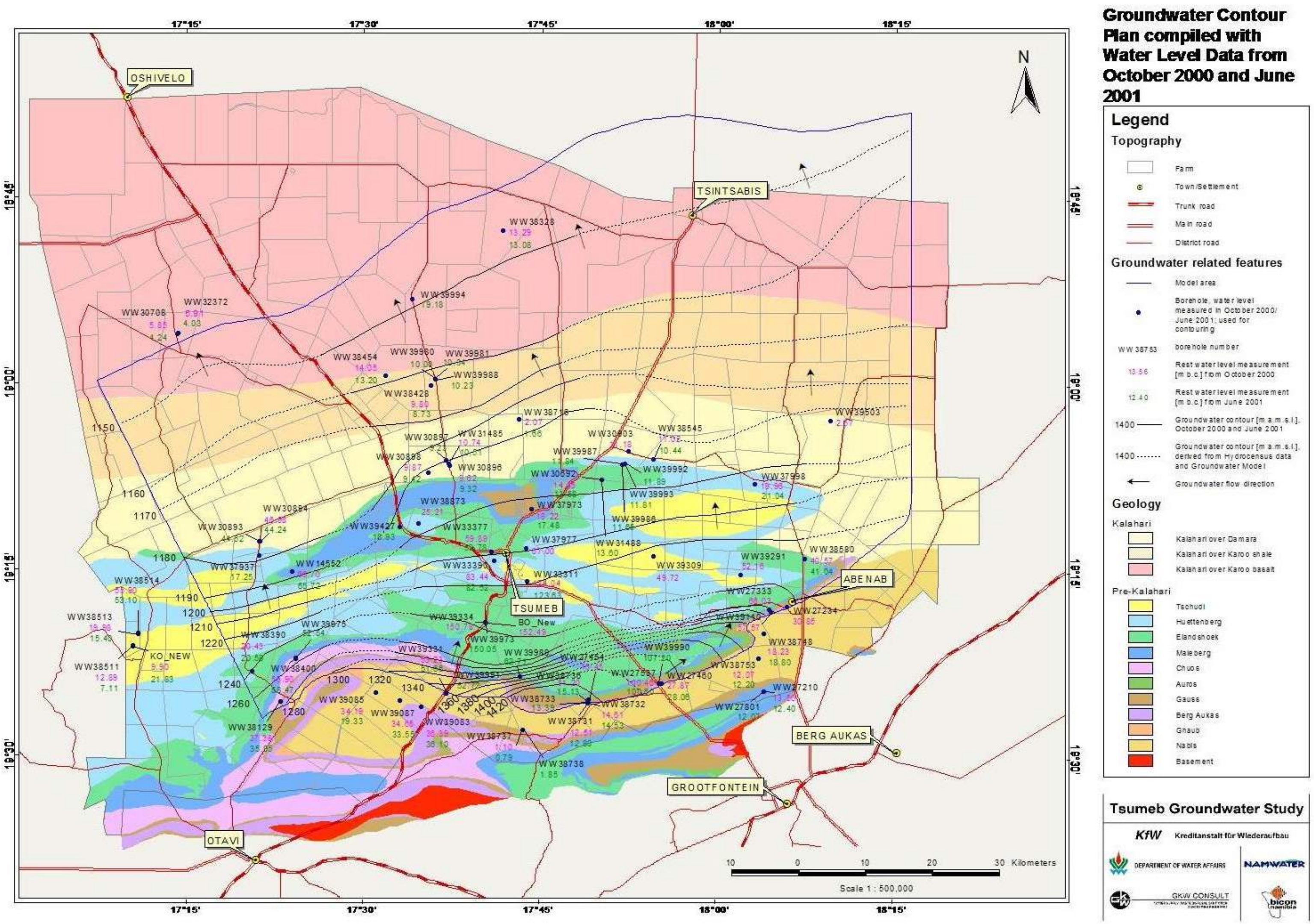

FIGURE 12: REGIONAL GROUNDWATER FLOW DIRECTION (GKW CONSULT / BICON 2003)

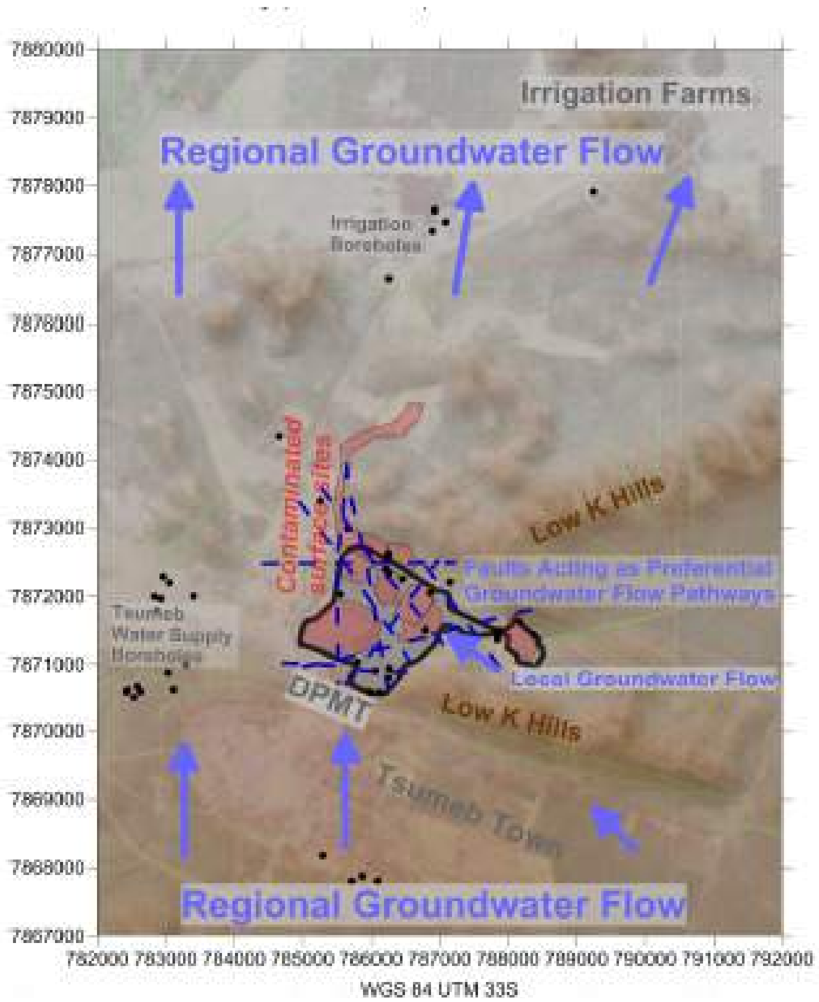

FIGURE 13: CONCEPTUAL DPMT GROUNDWATER MODEL (SOURCE: GCS, 2013)

Group or Subgroup	Group or Formation	Hydrogeological Unity
	Mulden (Kombat)	Aquiclude
Otavi (Tsumeb)	Hüttenberg	Unit 3c: Fractured/Karstfied Aquifer
	Elandshoek	Unit 3b: Fracture Aquifer
	Maieberg	
	Chuos	Unit 3a: Auitard
Otavi (Abenab)	Auros	Unit 2: Aquiclude
	Gauss	Unit 2: Fracture/Karstified Aquifer
	Berg Aukas	
Nosib Group	Varianto, Askevold, Nabis	Unit 1: Aquiclude
	Basement Complex	

FIGURE 14: HYDROSTRATIGRAPHY (MUKENDWA, 2009)

2.5 WATER ABSTRACTION

Requests have been made to the Client for details of any abstraction and discharge permits that are in the possession of DPMT for the smelter site. It is known that relatively large volumes of water are abstracted from Mine Shaft 1 (current installed pumping capacity of about 300 m^3/h) for use at the smelter site (Worley Parsons, 2015), but no abstraction permits has been approved for this. It is also known that the new sewage treatment plant discharges to the reed beds, but no discharge permit has been awarded for this or other effluent discharged on site. Additional information in this regard is provided in Chapter 4.5 below. Requests have been made to the Client for abstraction and discharge data, but none has been provided at this stage while the water balance is being updated, but not available yet.

The town of Tsumeb receives borehole water from a scheme situated to the west of the town, next to the Municipal dump site (Figure 17). The abstraction volumes and the influence on the groundwater regime, coupled with water abstraction from the mine shaft were not considered by GCS. SLR strongly recommends these parameters to be incorporated into a new groundwater model which ideally would not strictly focus on the smelter itself, but which should include at least the recharge area and the main abstraction areas as well.

2.6 SMELTER EXPANSION

The proposed smelter expansion would be contained within the existing site footprint and would include the following components, to enable the copper concentrate processing capacity to increase from 240 000 t/a to 370 000 t/a:

- Upgrading of the existing Ausmelt feed and furnace;
- Installation of a rotary holding furnace (RHF);
- Implementation of slow cooling of the RHF and converter slag;
- Upgrading of the slag mill to improve copper recovery and handle the increased tonnage from slow cooled slags;
- Installation of an additional Peirce-Smith (PS) converter;
- Closing down of the arsenic plant; and
- Additional related infrastructure improvements (power supply, etc.).

One of the most significant changes that will impact on the groundwater is the planned increase in abstraction of water from the shaft from the current 300 m^3/h (from Shaft 1) to approximately 375 m^3/h, for supplying in the raw water needs of the increased processing capacity (Worley Parsons, 2015). This figure will need to be verified through further detailed studies and with the updating of the site water balance.

3 DUNDEE SMELTER EXPANSION GROUNDWATER STUDY

3.1 SCOPE OF WORK

The scope of work is to review the groundwater monitoring network and sampling procedures for QA / QC purposes. A gap analysis to evaluate risks generated by potential pollution (low, medium, high) is also part of the study.

A critical review will be undertaken of external documentation provided by the client focusing on the work GCS undertook since 2013 at DPMT, known then as NCS (Namibia Custom Smelter). Under critical review are the following reports:

- GCS (2013) NCS Groundwater Data Review and Monitoring, Final Version, 01st May 2013, Ref PO00008185 Document 12-056
- GCS (2013) NCS Groundwater Flow and transport Model, Version 1, 17th July 2013, Ref PO00008185 Document 12-056
- Golder Associates Africa (Pty) Ltd (2013) Dundee Precious Metals Tsumeb: Closure Plan, November 2013, Report No. : 13614914 - 12263 - 1
- GCS (2014) Tsumeb Water Supply and Smelter Studies, Phase 4: Smelter Sinkhole Risk and Contaminant Plume Mapping, Draft Report, Version 1, 02nd December 2014, 13-050 Document GCS13-050
- GCS (2016) Tsumeb Smelter Groundwater Model Update, Report, Version 1, 04th March 2016, 14-803 Document GCS.

The groundwater monitoring network as well as groundwater modelling studies address EBRD PR3 Section 19 which states *"The client will need to consider the potential cumulative impacts of water abstraction upon third party users and local ecosystems. Where relevant, the client will assess the impacts of its activities on the water supply to third parties and will need to demonstrate that its proposed water supply will not have adverse impacts on the water resources crucial to third parties or to sensitive ecosystems. As part of the client's environmental assessment process, the client will identify and implement appropriate mitigation measures that favour the prevention or avoidance of risks and impacts over minimisation and reduction in line with the mitigation hierarchy approach and good international practise."*

3.2 REVIEW ON GROUNDWATER MODELLING

The current groundwater model for DPMT is very simplistic and can be regarded is a low confidence, high level model. An improved model that accounts for the more complicated geology of the area and that relies on new boreholes (still to be drilled) to provide water level, geological, geophysical and chemical data, need to be developed for more accurate predictions on plume migration and the impact of groundwater abstraction. Such a model should build on the existing model for the area done during the Tsumeb Ground Water Study (TGWS) in 2003 (GKW CONSULT / BICON, 2003).

3.3 REVIEWING THE PREVIOUS GROUNDWATER REPORTS

3.3.1 PRELIMINARY ASSESSMENT OF THE CONTAMINATION RISKS TO THE GROUNDWATER REGIME AT THE TSUMEB SMELTER, REPORT 2, DECEMBER 2009.

The report focussed on reviewing desktop information on the source chemistry and groundwater quality for the smelter site, as well as describing the groundwater associated risk, mitigation actions and recommendations for future groundwater monitoring. A number of leach tests were done on the various potentially contaminating materials occurring on site. The following findings and recommendations came from the report:

- The slag mill tailings had elevated levels of trace elements in it, but are largely contained in the tailings dumps itself, due to the very high natural buffer capacity of the underlying dolomitic soils. It was concluded that it is unlikely for this dump to impact on the ground water due to the water level being more than 80 m bgl.
- Reverberatory slag showed elevated levels of trace elements. It was proposed at the time to use this slag as a leachate collection layer material for the hazardous waste site. This was concluded to be a feasible use, since the slag would still be in the “dirty” system and has much lower concentrations of pollutants than the planned waste to be stored in the site. It was recommended that accelerated weathering tests be done on the slag to confirm its structural ability needed for such a layer in the hazardous waste site.
- It was concluded from the leach tests that the blast furnace slag was unlikely to contaminate the groundwater.
- Monitoring results from the smelter borehole (to the west of the new tailings dam) showed drinking quality water to be present, though arsenic concentrations has become higher in recent samples. It was recommended that monitoring boreholes be drilled to the north of the new tailings dam to ensure the general flow direction of the groundwater gets monitored. Further to this, it was also recommended that a detailed geo-hydrological study be conducted on the new tailings dam area, should the facility be recommissioned.

- A number of trace elements were found to be elevated in the old tailings dam material and it was recommended that monitoring boreholes be drilled downgradient of this facility, since none were in place at the time.
- The converter slag was shown to be unlikely to contaminate groundwater based on the leach tests' results.
- The arsenic calcines were found to have very high concentrations of leachable sulphate, calcium, magnesium, cadmium, copper, manganese, lead, arsenic and zinc. It is a highly acid material, which will mobilise even more metals and it was strongly recommended that the dumps be covered with an engineered cover. The drilling of monitoring boreholes downstream of the dumps was also recommended.
- Converter dust was showing very high concentrations of trace elements from the leach tests and it was indicated at the time that this material would be moved to the planned hazardous waste storage site. It was recommended that the material be moved to the hazardous waste site as soon as possible and that further monitoring boreholes be drilled to the north of the current storage area. Three monitoring boreholes were also recommended to be drilled at the new hazardous waste site.
- The tar pits had some polycyclic aromatic hydrocarbons present in the surface water found on them at the time. It was concluded that these had a very low risk of contaminating groundwater and it was recommended that a monitoring borehole be drilled north of the tar pits to verify the movement of hydrocarbons into the groundwater.

3.3.2 NCS GROUNDWATER FLOW AND TRANSPORT MODEL, VERSION 1, JULY 2013

The report was the outcome of Phase 2 of the groundwater study undertaken for Namibia Custom Smelters (NCS) on the Tsumeb Smelter site. The main objective of Phase 2 was to determine the aquifer characteristics for the site and developing a flow and transport model, which could produce predictions of possible future water qualities, both on and off-site. The following findings and recommendations came from the report:

- Knowledge gaps at the time:
    - No time series data on water levels was available.
    - No information regarding vertical gradients in the aquifer was available.
    - No pumping history of boreholes at the NCS site was available.
    - No information on historical management of slag heaps and the tailings dams over time were available.
    - No information about the calcine heaps and its contribution to contamination.
    - No information about the tailings dams and their contribution to pollution.

  - No information about the return water dams, their water holding capability or contribution to pollution.
  - No information regarding run-off events and their management on site
  - No spatial information for the areas north of the site where the modelled plume is possibly moving into.
- The groundwater model showed most sensitivity to changes in recharge and hydraulic conductivity. Time series data with estimates of groundwater level response in relation to rainfall recharge will be of great benefit in future model updates.
- The MT3D package was used to calculate contaminant flows from the site. Potential contaminant plumes were mapped based on these models. The plume movement was shown by simulations to be in a northerly direction and not always flowing according to surface topography. Arsenic was used as the indicator pollutant. Contamination build up was simulated based on surface water from contaminated sources and the return water dam regarded as being the most significant source of pollution.
- The simulated plume for 2013 was correlated to 2012 sampling data and found to be representative of the situation existing at the time. It indicated that the arsenic plume had already reached the irrigation farms north of the smelter in 2013.
- Future predictions based on the 2013 data were then undertaken and showed that if liners were installed into return dams, significant reduction in off-site contamination would be realised.

3.3.3 NCS GROUNDWATER DATA REVIEW AND MONITORING, VERSION FINAL, MAY 2013

The report covered information already available on site, including monitoring data and geological and hydrogeological information. The following was highlighted:

- The site falls on the regional dolomitic groundwater system, which provides water to the town, the nearby farms and the ecosystem.
- The data from the current available monitoring program indicated some suspect figures and the sampling procedures for the boreholes were deemed to be incorrect, leading to most of the data being discarded as not being useful. This was further complicated by apparent mistakes in numbering of boreholes and its correlation to reported data. Limited data was available on borehole depths and construction.
- A hydrocensus was conducted in November 2012, equipped boreholes were sampled by purging to a constant discharge quality before sampling, while unequipped boreholes were sampled by a discreet interval sampling technique at different depths, based on fluid logs from down-the-hole probing.

- Outliers identified when comparing the latest sampling data to the historical data were attributed to the differences in sampling methodology.
- Water levels measured at on-site boreholes were used to map the groundwater piezometric head on-site and indicated no discernible cone of depression caused by groundwater abstraction (Figure 15).

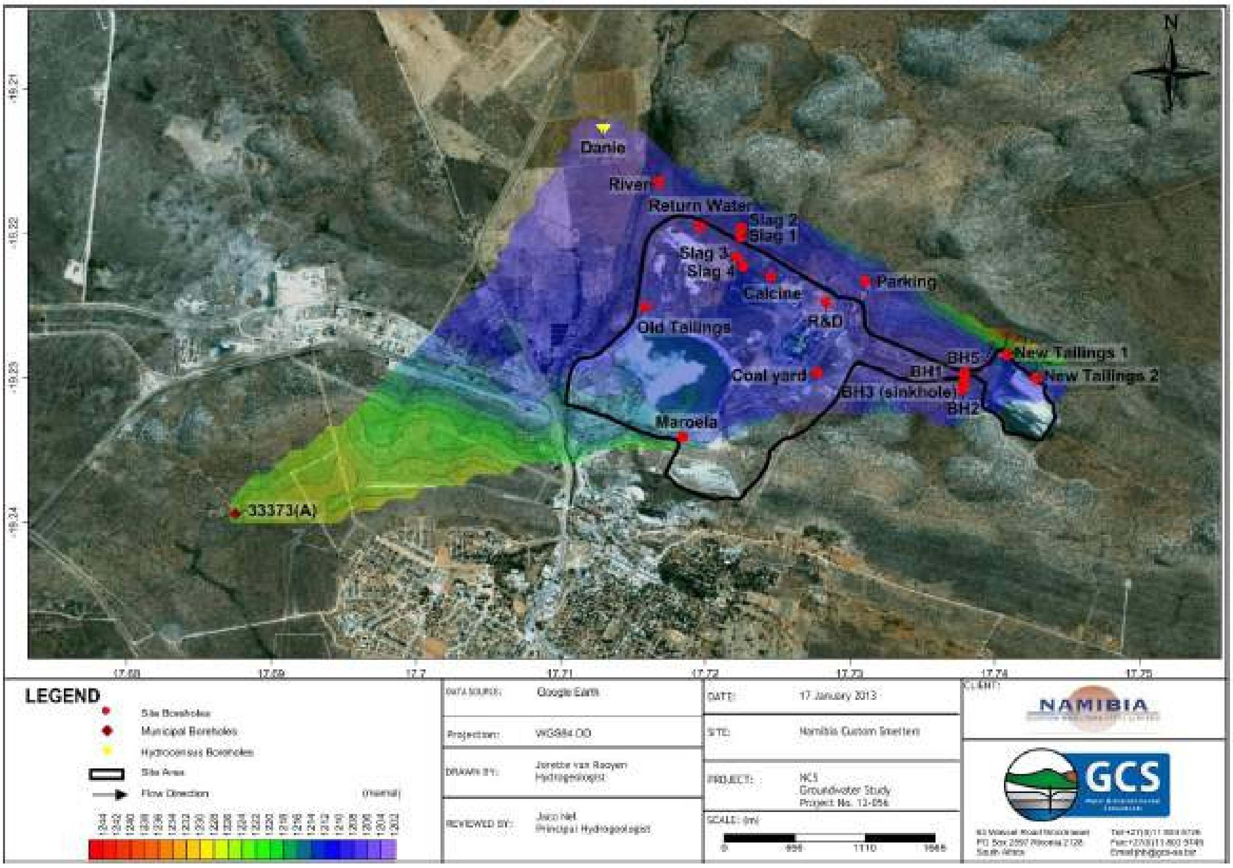

FIGURE 15: A MAP INDICATING THE PIEZOMETRIC HEAD IN THE SMELTER AREA BASED ON WATER LEVEL MEASUREMENT REPORTED IN MAY 2013 (GCS. 2013).

- The report highlighted gaps in the current sampling on-site and a short sampling procedure was described to improve the future data, with some on-site training in this procedure having been given to site personnel.
- The following recommendations were made:
  - Numbering of boreholes should be fixed and field numbers applied to the borehole collars.
  - Recording of water levels before purging/sampling.
  - Discreet interval sampling at different levels should be done on all open boreholes.
  - Pump depths should be aligned to main flow zones in equipped boreholes to shorten purging times and potential surface contamination.

- All boreholes should have two samples taken from them: one unfiltered for major anion analyses, and one filtered and acidified for trace element analyses.
- A two yearly update of the groundwater model should be undertaken based on the collected data.

3.3.4 Closure Plan Report for Dundee Precious Metals Tsumeb, November 2013

The report has been commissioned to assist DPMT to proactively plan and mitigate possible impacts, and associated liabilities, for the smelter operations. The plan is to ensure a seamless progression from operations to closure with the least possible post-closure liability. The following recommendations and conclusions were made that relate to groundwater management:

- The closure-focussed risk assessment, subsequent closure planning undertaken, as well as the soil survey undertaken as part of the Acid Plant EIA phase, identified the need for dedicated technical work to inform rehabilitation of the site, including:
  - Full (site-wide and neighbouring land) contaminated land assessment to identify possible areas of contamination that require attention;
  - Waste classification (source term characterisation) of the waste residues; and
  - Dedicated unsaturated flow modelling (net footprint percolation) for the above to determine the footprint waste loads of the waste sites and to assess optimum cover thicknesses utilising the available soil resources to limit moisture ingress into the facilities.
- As continuation to the existing GCS groundwater studies, a geophysics survey with the following objectives was underway at the time of reporting:
  - Define the structural geology of the formations underlying the DPMT smelter complex with respect to dolomitic grikes, dolines and cavities, aquifers, aquicludes, and structures that could act as preferential pathways for groundwater recharge and shallow groundwater (< 40 m), and including groundwater pollution plumes;
  - Locate and define aquifers;
  - Determine the presence and localities of dolomitic cavities and evaluate the risk of sinkhole formation at the DPMT Smelter, including a determination of the karst topography; and

  - Locate and define the aerial extent of seepage plumes and other groundwater occurrences in the unsaturated zone emanating from the tailings dams and water storage dams.
- To further refine closure planning, and based on the above technical investigations, a site-wide rehabilitation plan is to be compiled that focuses on integrating closure planning and operational site management via progressive rehabilitation. Specifically, the following would be considered:
  - Formulation of practical and implementable rehabilitation objectives and associated measures to achieve a seamless transition of the operational area to the pre-determined post-operational land use/s;
  - Assessment of the extent of impacts on land and development, implementation, monitoring and refinement of rehabilitation methodologies in line with agreed closure objectives and measures;
  - Taking cognisance of local physical and landform conditions, such a local drainage lines and patterns as well as establishing a clear understanding of local soils conditions;
  - Addressing the phasing of concurrent rehabilitation and rehabilitation performed during the closure phase of the mine. Rehabilitation should be carried out as soon as possible in line with the closure objectives, without waiting for cessation of activities; and
  - Ensuring rehabilitation designs are based on adequate and scientifically sound information and, where relevant, integrated with site biodiversity and water management plans.

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3.3.5 TSUMEB WATER SUPPLY AND SMELTER STUDIES PHASE 4: SMELTER SINKHOLE RISK AND CONTAMINANT PLUME MAPPING, DRAFT REPORT 1, VERSION 1, DECEMBER 2014

The report reflects the results of a high level risk assessment for sinkhole formation in the Tsumeb area, as well as an update of the transport model developed in 2013, with new information from the geophysical study being incorporated. The following is a summary of the report findings:

- A conceptual groundwater model was developed in 2012 and updated in this report (Figure 13).
- The Otavi Group dolomite underlies the DPMT site.
- The primary recharge area is about 14 km to the south, with the discharge area 60 km to the north.

- The regional water level gradient is from south to north.
- DPMT is situated in an ESE-WNW sloping valley formed as part of an anticlinal structure.
- Groundwater is expected to move in fold axes, pressure relief joints, faults or on contact zones of changes in lithology.
- Tsumeb's water supply originates from boreholes situated to the west of the town, not far from the dump site.
- GCS (2012) couldn't obtain data from both NCS (Ex-DPMT) and GRN, as far as RWL are concerned at the time of writing their report.
- GCS (2012): the influence of abstraction from the old mine shaft isn't clear from the limited water level data. Apparently 2 Mm^3/a are abstracted for both NCS and Town uses.
- GCS (2012): lower hydraulic conductivities found associated with the dolomitic formations on the sides of the valley, with higher hydraulic conductivities associated with the dolomitic formations at the centre of the valley.
- GCS (2012): General groundwater piezometric heads at the sites indicates a local flow system passing underneath the site in a NW direction, contributing to the larger Tsumeb regional dolomitic aquifer.
- A need was identified at the time for a water balance, at least qualitative, to understand the origin of water, use of water and rejection of water.
- A numerical model was constructed using the modelling code MODFLOW, while MT3D, with the aid of Groundwater Vistas 6 software was used to model the pollution plume movement.
- The sinkhole risk assessment identified three risk areas (Figure 16):
    - Dolomite Stability Risk Area 1: Located south-southeast of the old tailings area. It is characterised by several small to intermediate size gravity lows. A larger gravity low anomaly exists to the southeast of the old tailings area and could be attributed to a complex geological structure.
    - Dolomite Stability Risk Area 2: This area is elongated along the north-eastern boundary of the site. It is characterised by several irregular spaced small to intermediate size gravity lows. It tends to follow northwest-southeast trending structural features, which also corresponds to the hill outcrops, caused by slight changes in dolomitic composition in the area.
    - Dolomite Stability Risk Area 3: It is made up of gravity low areas to the northwest and southwest of the New Tailings facility. It could be associated with the presence of dykes in the area.

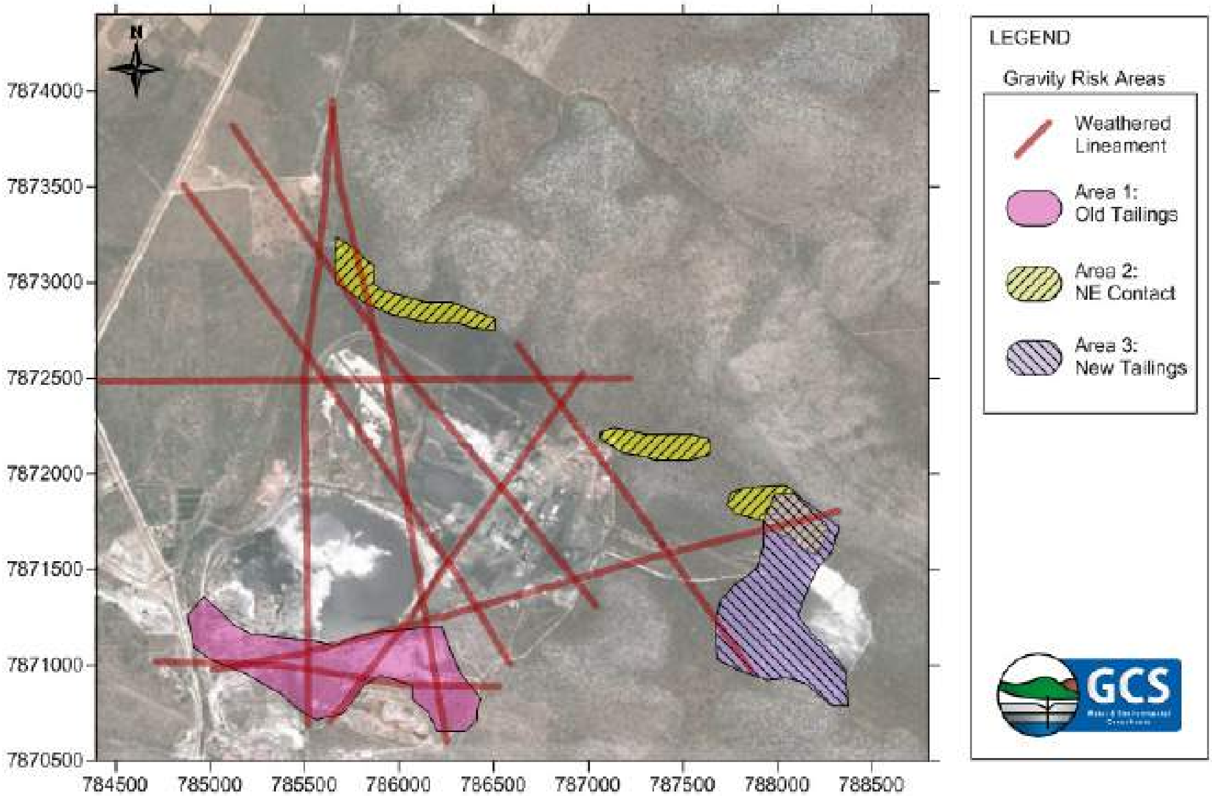


FIGURE 16: DOLOMITE STABILITY RISK AREAS BASED ON GEOPHYSICAL DATA INTERPRETATION (GCS, 2014)

- The following management measures against stability risks were recommended:
  - Drilling and geological mapping to confirm the lineament positions, the depth of weathering and geometry of karst cavities (this should be carried out before any development is considered in these areas).
  - Preventing localised groundwater ingress near any infrastructure.
  - A detailed monitoring programme evaluating both groundwater quality (to alert change in chemistry that could enhance dissolution of rock and sinkhole formation) and groundwater level fluctuation.
- The following sources of potential contamination were identified at the time:
  - Return water dam
  - Surface water runoff from site
  - Slag and calcine dumps
  - Tailings dams
- The following recommendations were made at the time:
  - Lining of the return water dam is essential;
  - A detailed hydrocensus is needed on all boreholes around the site and to the north on the neighbouring farms;

  - Extra boreholes to be drilled 500 m to 1,000 m to the north of the site;
  - Aquifer tests on the boreholes to the north of the site to be undertaken;
  - Water level time series data should be collected in future;
  - Additional characterisation of the aquifer needs to be carried out to quantify existence of vertical heads and different flow zones in the system;
  - Fluid electrical conductivity logging of boreholes needs to be carried out to determine the potential existence of flow zones and assist in characterising vertical properties of aquifers;
  - Geochemical characterisation of the slag piles, calcine heaps and tailings on site is needed;
  - Geochemical source characterisation as well as adsorption / retarding characteristics of the dolomitic rock should be conducted to provide current and representative contamination loads to the aquifer;
  - The test drilling and pump testing of selective geophysical anomalies are recommended for the calibration of the geophysical data.

3.3.6 TSUMEB SMELTER GROUNDWATER MODEL UPDATE, REPORT 1, 04 MARCH 2016

The report focussed on updating the groundwater model for the smelter area with emphasis on the boundary conditions, chemical retardation processes impacting the transport model predictions and simulating different chemical transport scenarios.

The following findings and recommendations were listed:

- Hydrocensus:
  - 49 boreholes were visited;
  - Off-site boreholes shows a clear calcium-magnesium bicarbonate character;
  - Site boreholes (boreholes inside the smelter site) showed a calcium-sodium-sulphate character due to the onsite impacts from the smelter;
  - Detectible selenium concentrations were found in private boreholes, with much higher selenium concentrations found in the boreholes associated with the slag dumps, calcine dumps and smelter;
  - It was recommended that selenium and molybdenum also form part of constituents being monitored in off-site boreholes in future.

- Arsenic adsorption
  - Batch adsorption tests, using Tsumeb dolomite material, indicated significant reduction in arsenic concentration for both high and low concentrations of arsenic in the source water. This was relevant for dolomite material not previously contaminated;
  - The pH condition existing at the site is conducive to precipitation of arsenic in the presence of iron containing minerals. The iron saturation in the aquifer is not high enough to cause significant precipitation of arsenic on-site and the fact that a legacy of more than 100 years of contamination exists, would have caused the system to have reached equilibrium on-site. This means that very little arsenic is being captured in the aquifer on-site, leading to contamination moving off-site;
  - It was recommended that further leach tests be done in leach columns to determine the saturation point for the level of contamination that would lead to saturation of the adsorption/precipitation matrix.

- Numerical groundwater model:
  - The 2014 conceptual model was revisited and the numerical model based on this was updated;
  - A model simulating the last 108 years of operations at the smelter has been developed taking water abstraction and changing sources of potential contamination over time into account, with assumed numbers due to the lack of available historical data. This was done using a steady state flow field developed from the calibrated groundwater model for the site;
  - A predictive transport model was used to predict the risk of contaminating the groundwater of private groundwater users to the north of the smelter site. Porosity and hydraulic conductivity contributes most to the uncertainty in the model;
  - The arsenic plume prediction was run for the year 2038, and showed that the plume will continue to migrate to the north, with off-site boreholes closer to the site potentially ending up with arsenic concentrations higher than the Namibian drinking water limit of 0.3 mg/l. It is also stated that the modelled predictions could be too low, due to the uncertainty related to existence of fractures, faults and other geological structures. (Figure 17).

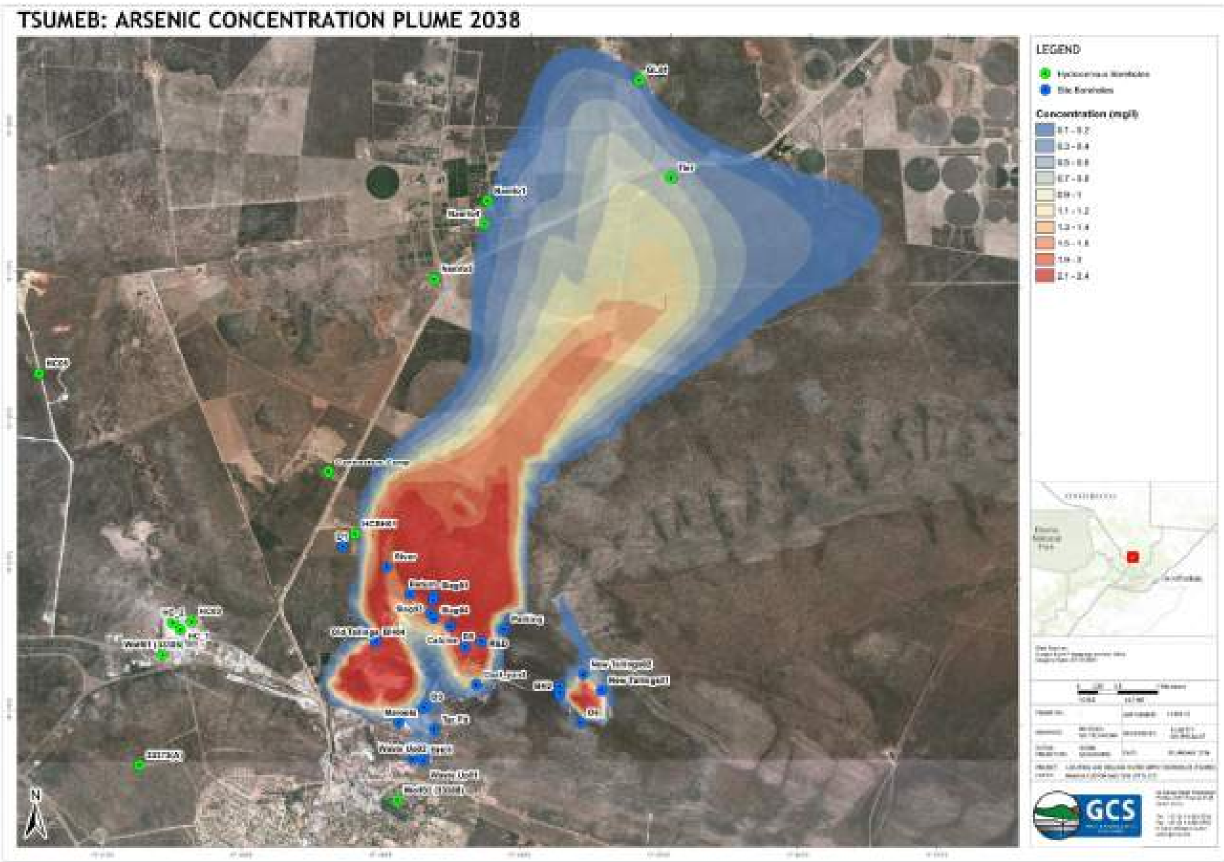


FIGURE 17: A MAP DEPICTING THE EXTENT OF THE MODELLED ARSENIC PLUME BY 2038 WITH NO REMEDIATION BEING UNDERTAKEN. (GCS, 2016)

- Remedial measures:
  - Abstraction of water from boreholes named Slag 1, Slag 2, Slag 3 and Slag 4 was evaluated as a remedial measure to retard further plume migration. It showed that up to 3.8 kg of arsenic can be removed per day (pumping rate of 2,496 m^3/day). This will reduce the end of operations arsenic concentrations in the aquifer on-site, but show no significant reduction in the northward migration of the arsenic plume;
  - The old tailings, slag dump and return water dams contributes the largest portion of the arsenic contamination. The rehabilitation of these facilities could have a significant reduction in future arsenic load entering the aquifer, but will not significantly reduce the plume extent;
  - Additional arsenic removal by scavenger wells and bio-remediation was recommended.
- Additional recommendations:
  - Drilling of further monitoring boreholes north of the smelter to get a better idea of the hydraulic characteristics of the aquifer;

- More frequent sampling of the private boreholes north of the site;
- Selenium concentrations to be included in reporting of future monitoring results;
- Redox potential for in-situ aquifer conditions should be evaluated;
- Vertical gradient information might be needed to further refine the transport model, based on the existence of horizontal fractures, bedding planes and other stratified geological flow impacts.

3.3.7 REVIEW OF GROUNDWATER MONITORING

SLR has received groundwater monitoring data for the smelter site in spreadsheets. The data covers the period from February 2012 to July 2015. As highlighted in the previous reports, some confusion still exists regarding the borehole numbers and the correct site co-ordinates linked to each. The names used for the boreholes in historical reports are used for the sake of continuity. Some constituents have also not been analysed for in all boreholes and some obvious data anomalies exist in terms of reported values.

A number of progress reports have been written regarding the status of sampling and monitoring on site. The latest available to SLR was dated 10 February 2016 and relates to the sampling frequency and constituents to be analysed for (GCS, 2016). Based on the advice received in these progress reports, the Client has changed the sampling methods, making it difficult to compare the historic data to the latest data. The following has been recommended in the latest progress report:

- Due to the inconsistency of the data it was recommended that current sampling methods be used for another twelve months of monthly sampling to build a baseline data base, which will then inform the decision on sampling frequency in future;
- A minimum list of constituents to be analysed for was suggested as follows:
  - pH at 25°C
  - Electrical Conductivity at 25°C
  - TDS at 180°C
  - Total alkalinity
  - Calcium
  - Magnesium
  - Sodium
  - Potassium
  - Chloride
  - Sulphate
  - Nitrate as N
  - Barium
  - Cadmium
  - Chromium
  - Cobalt
  - Copper
  - Iron
  - Lead
  - Manganese
  - Molybdenum
  - Vanadium
  - Zinc

- Aluminium
- Arsenic
- Selenium

- The sulphate analyses results looks suspect and an alternative laboratory had been suggested to do future analyses;
- Borehole “Waste Up 1” needs to be re-drilled due to a collapse in the original borehole.

DPMT has also produced a report on water quality at the Ondundu Community south east of the smelter in June 2016, in which analyses of the drinking water originating from local boreholes were discussed. Samples were taken from taps at three locations in Ondundu and were analysed. All the samples were within the Group B drinking water quality for Namibia, and this quality was only due to high levels of hardness detected. The arsenic content was well below any of the Namibian Guideline values for drinking water (Dundee Precious Metals Tsumeb, 2016).

3.4 Groundwater Quality

It is important to view the groundwater quality monitoring results against some background values for the larger karst region, specifically when looking at arsenic pollution. Data from wider area studies does indicate elevated arsenic concentrations in areas not previously affected by mining. Figure 18 from the Tsumeb Groundwater Study (GKW Consult / BICON 2003) indicates an arsenic concentration of 0.11 mg/l at borehole WW38837, much further to the north east than any of those sampled in current studies commissioned by the smelter. Concentrations of 0.05, 0.07 and 0.05 mg/l were measured at boreholes WW38445, WW37893 and WW37894 respectively.

For the last round of groundwater sampling (July 2015) by DPMT at the various boreholes on site the old sampling method was still used. Figure 19 indicates the location of the boreholes on a map and Table 3 lists the co-ordinates where the boreholes are located. Table 4 indicates the water quality data that was available from this July 2015 sampling.

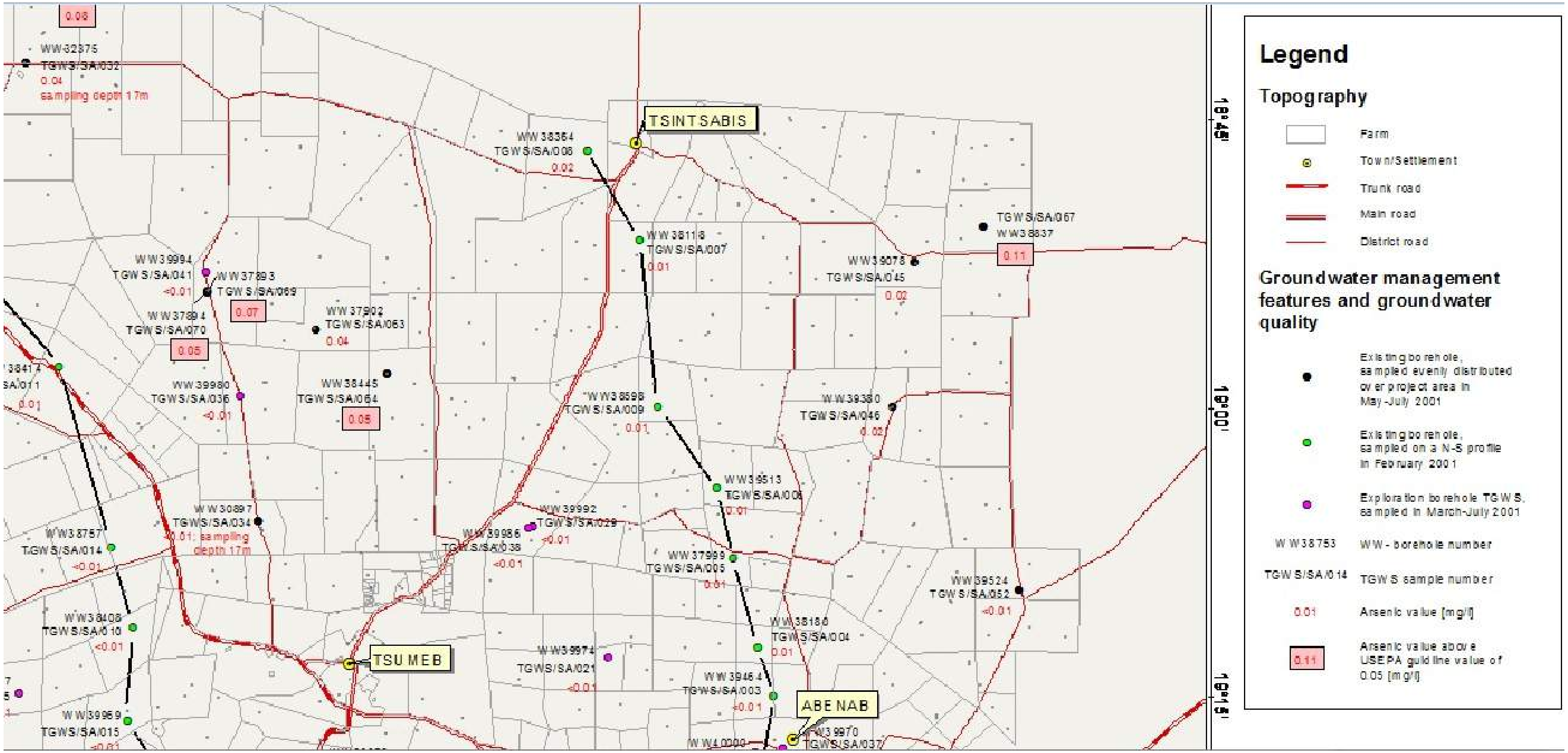


FIGURE 18: MAP INDICATING ARSENIC CONCENTRATIONS IN GROUNDWATER IN THE WIDER TSUMEB AREA (GKW CONSULT / BICON 2003)

TABLE 3: LOCATION OF GROUNDWATER SAMPLING POINTS

Names	Longitude	Latitude
New Tailings 1	17.74281	-19.2301
Return	17.71967	-19.2195
Waste Up 2	17.72025	-19.2382
Calcine	17.72453	-19.2231
Parking	17.73101	-19.2233
River	17.71684	-19.2165
New Tailings 2	17.74063	-19.2283
Borehole 5	17.7264	-19.2254
Waste Up 1	17.72157	-19.2384
Waste Down (Tar Pit)	17.72287	-19.2348
Maroela	17.71848	-19.2341
Old Tailings	17.71565	-19.2250

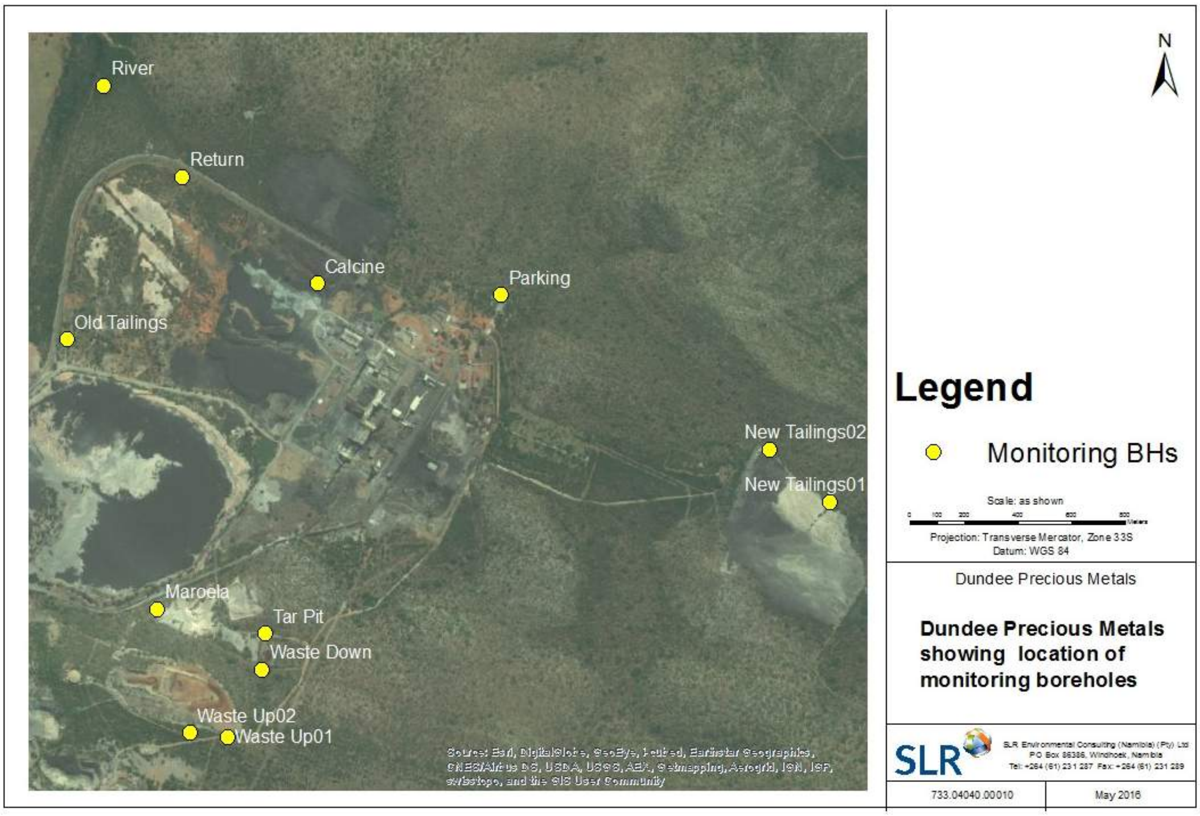


FIGURE 19: MAP INDICATING THE LOCATION OF THE MONITORING BOREHOLES ON THE SMELTER SITE.

Arsenic content has been highlighted as the main signature constituent for indicating pollution by the smelter and is also of most concern to the neighbouring groundwater users. The figures below thus focus on the arsenic content measured in the boreholes with Figure 20 showing graduated circles of arsenic concentration for each of the boreholes for the July

2015 sampling. From this figure one can see that only the Calcine- and Return Boreholes are currently having arsenic concentrations exceeding the Namibian Guideline values for drinking water. All other boreholes have concentrations falling within the Group B or better quality for drinking water according to the Namibian Guideline. Figure 21 shows a time series graph of the arsenic concentrations since February 2012. From the graph, it is clear that the Calcine, Maroela and Return boreholes (right-hand axis of graph) have been impacted the most by the smelter, with arsenic concentrations up to 10 mg/l in the Calcine borehole and as high as 28 mg/l measured in the Return borehole for March 2014.

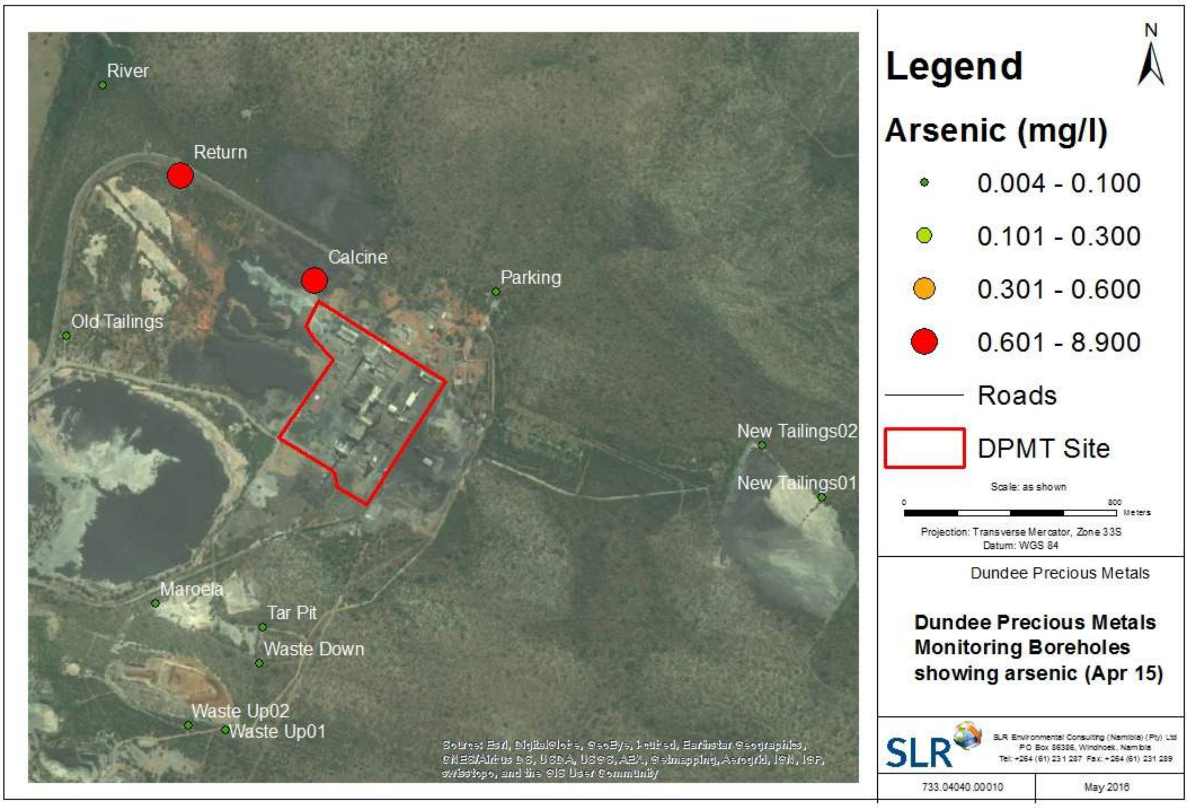
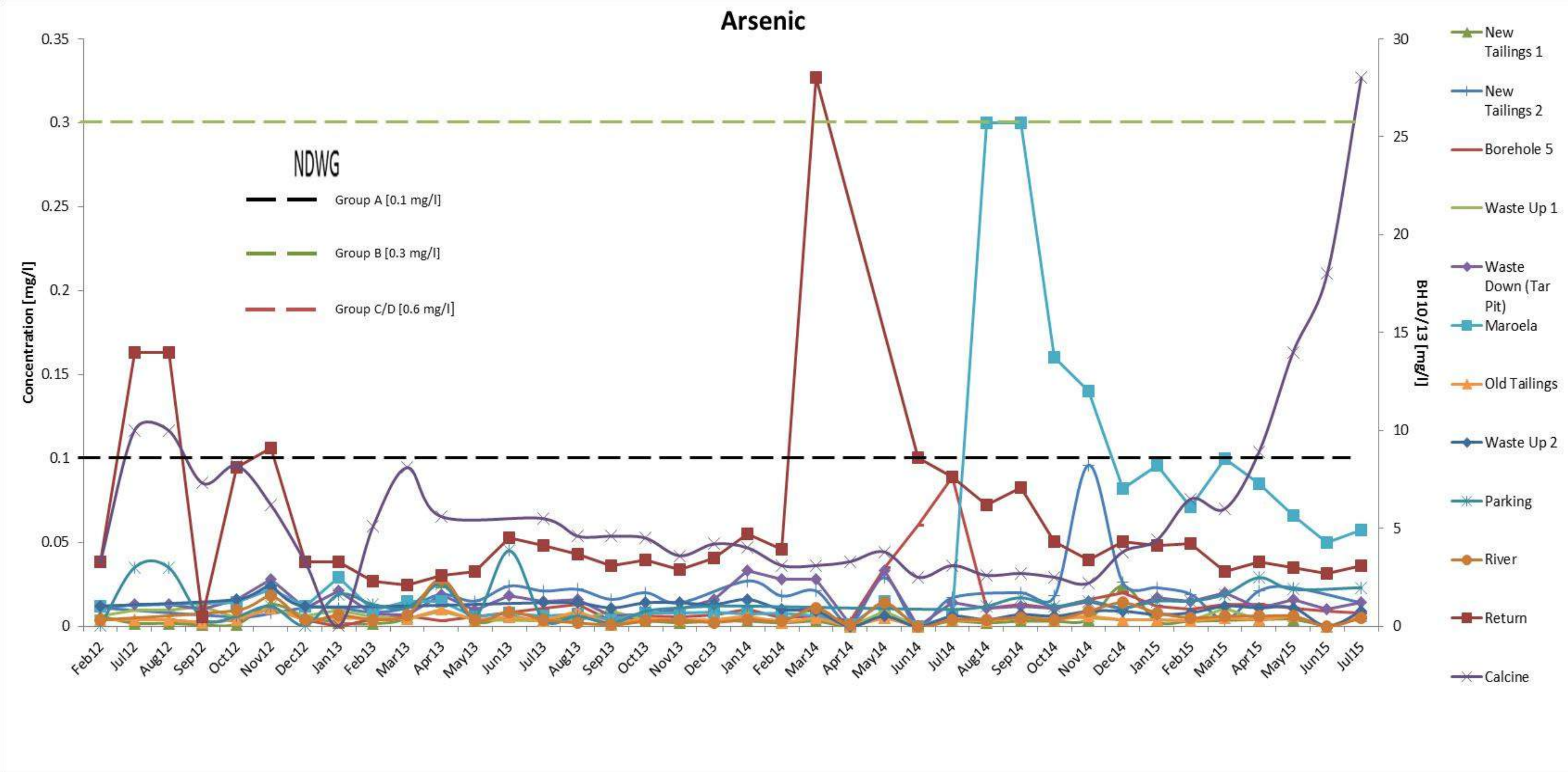


FIGURE 20: A MAP INDICATING THE ARSENIC CONCENTRATIONS IN THE MONITORING BOREHOLES ON SITE FOR JULY 2015.

TABLE 4: ANALYSES RESULTS FOR THE SAMPLES TAKEN IN JULY 2015 FROM BOREHOLES ON THE SMELTER SITE.

Constituents	Unit	Namibian Drinking Water Guidelines				WHO Drinking Water (2012)	New Tailings (BH2)	Borehole #5 (BH4)	Calcines (BH13)	Maroela (BH7)	Tar Pit / Waste Down (BH6)	Waste Up One (BH5)	Old Tailings (BH9)	Return Water (BH10)	Waste Up Two (BH11)	River (BH18)
		Group A	Group B	Group C	Group D		Mixed sample	Mixed sample	Mixed sample	Mixed sample	Mixed sample	Mixed sample	Mixed sample	Mixed sample	Mixed sample	Mixed sample
pH–Value at 25℃	-	6-9	5.5-9.5	4-11	4-11	NS	7.1	7.2	7.1	7.4	7.3	7.3	7.3	7.3	7.5	7.4
Electrical Conductivity	mS/m	150	300	400	400	NS	175	92	249	153	134	120	158	194	91	110
Total Dissolved Solids. at 180℃	mg/l	NS	NS	NS	NS	NS	1300	660	1900	1100	890	720	1000	1300	510	640
Calcium as Ca	mg/l	150	200	400	400	NS	178	115	237	180	141	135	159	162	99	124
Sodium as Na	mg/l	100	400	800	800	NS	98	15	205	77	46	42	99	151	12	36
Potassium as K	mg/l	200	400	800	800	NS	12	2.6	16	7	4.3	4.9	5.8	15	2.3	4.2
Total Alkalinity as CaCO3	mg/l	NS	NS	NS	NS	NS	355	463	315	375	385	380	433	388	360	420
Chloride as Cl	mg/l	250	600	1200	1200	NS	23	9.7	131	60	31	42	70	124	15	33
Sulphate as SO4	mg/l	200	600	1200	1200	NS	531	43	900	410	267	151	309	484	58	93
Nitrate as N	mg/l	10	20	40	40	NS	1.7	0.67	1.3	0.6	0.89	4.8	4.7	0.54	0.15	2.5
Fluoride as F	mg/l	1.5	2	3	3	1.5	<0.05	0.12	<0.05	0.11	<0.05	<0.05	<0.05	<0.05	1.2	<0.05
Nitrate as NO3	mg/l	NS	NS	NS	NS	50	7.5	3	5.6	2.6	3.9	21	21	2.4	0.7	11
Mercury as Hg	µg/l	5	10	20	20	6	0.006	<0.001	0.24	0.032	0.029	0.005	0.066	0.047	0.001	0.004
Lead as Pb	mg/l	0.05	0.1	0.2	0.2	0.01	0.28	0.003	0.001	0.001	0.014	0.001	0.047	0.001	<0.0005	0.003
Manganese as Mn	mg/l	0.05	1	2	2	0.4	0.25	<0.002	<0.002	0.012	1.7	<0.002	0.002	0.87	<0.002	0.008
Arsenic as As	mg/l	0.1	0.3	0.6	0.6	0.01	0.014	0.008	28	0.057	0.014	0.005	0.006	3.1	0.009	0.005
Cadmium as Cd	mg/l	0.01	0.02	0.04	0.04	0.003	0.001	<0.0001	0.004	<0.0001	<0.0001	<0.0001	0.002	<0.0001	<0.0001	<0.0001
Cobalt as Co	mg/l	0.25	0.5	1	1	NS	0.029	<0.0004	0.001	0.002	0.054	<0.0004	0.001	0.015	0.001	<0.0004
Copper as Cu	mg/l	0.5	1	2	2	2	3.8	0.004	0.008	0.009	0.014	0.006	0.046	0.008	0.005	0.01
Iron as Fe	mg/l	0.1	1	2	2	NS	15	0.51	1	0.79	0.94	0.64	0.75	0.78	0.46	0.56
Zinc as Zn	mg/l	1	5	10	10	NS	0.43	0.12	<0.05	<0.05	<0.05	<0.05	0.07	<0.05	<0.05	<0.05
Molybdenum	mg/l						0.021	0.003	2.7	0.009	0.022	0.001	0.002	0.12	0.01	0.005



(The right hand axis of this graph indicates values for the Return, Maroela and Calcine boreholes).

FIGURE 21: A TIME SERIES GRAPH INDICATING THE ARSENIC CONCENTRATION MEASURED IN THE SITE BOREHOLES SINCE FEBRUARY 2012

3.5 CONCLUSIONS AND RECOMMENDATIONS

The conclusion from the investigation of the groundwater work which has been undertaken in the last few years at the DPMT site, is that there is a large amount of published material relating to various studies, including modelling, a reasonable amount of water quality data and a number of plans for groundwater monitoring and new boreholes. However, most of the action on the ground has been focused on improving the monitoring network within the smelter site, where significant pollution has already occurred, to monitor this; checking for any increasing or decreasing trends. It is clear that the waste storage facilities (calcines, slag, tailings and return water dams) are major sources of pollution. Monitoring results and groundwater modelling indicates that this pollution is moving off-site, to the north of the smelter and will continue to do so unless remedial action is taken.

See Table 5 for a summary of recommendations and the execution of these since 2009.

TABLE 5: LIST OF RECOMMENDATIONS MADE IN VARIOUS GROUNDWATER REPORTS FOR DPMT SINCE 2009

Report	Recommendation	Action taken
Preliminary Assessment of the Contamination Risks to the Groundwater Regime at the Tsumeb Smelter, Report 2, December 2009	Use reverberatory slag as a leachate collection layer for the hazardous waste disposal site.	Unsure.
	Do accelerated weathering tests on the reverberatory slag, should it be used as a leachate interception layer in the hazardous waste disposal facility.	Unsure.
	Drilling of monitoring boreholes to the north of the new tailings dam.	Done. Additional boreholes planned for 2017. Most critical ones still to be identified.
	Detailed geo-hydrological study should be done if the tailings dam is ever to be recommissioned.	N/a
	Drilling monitoring boreholes downgradient of the old tailings facility.	Additional boreholes planned for 2017. Most critical ones still to be identified.
	The arsenic calcine dumps should be covered by an engineered cover to reduce polluted seepage into the groundwater.	Terms of reference for a study into pollution control developed. ToR to be sent to market soon for tender purposes.
	Drilling of monitoring boreholes downgradient of the arsenic calcine dumps.	Done. Additional boreholes planned for 2017. Most critical ones still to be identified.
	Moving the converter dust to the hazardous waste disposal facility as soon as possible.	In progress – done as per plan.
	Drilling of more monitoring boreholes to the north of the converter dust storage area.	Additional boreholes planned for 2017. Most critical ones still to be identified.
	Drilling three monitoring boreholes at the hazardous waste disposal facility.	Additional boreholes planned for 2017. Most critical ones still to be identified.

Report	Recommendation	Action taken
	Drilling of a monitoring borehole to the north of the tar pits.	Additional boreholes planned for 2017. Most critical ones still to be identified.
NCS groundwater data review and monitoring, version final, May 2013	A new groundwater sampling method to be implemented	Done.
	Correct the borehole numbering on data and fix borehole numbers to the borehole collars to ensure correct numbering of samples	Done. In progress – all boreholes to be fitted with new signs indicating new numbers and coordinates.
	Recording of water levels in boreholes before purging or pumping	Done.
	Discreet interval sampling needs to be done on all open boreholes	Being done.
	Pump installation depths should be aligned with main flow zones in boreholes	Done. Pumps have been removed – new sampling method introduced.
	Borehole samples should be taken as two samples for each borehole; one treated for metals analyses and one for major ion analyses	Done. This might change in future, depending on sampling programme.
	Groundwater model should be updated every two years.	Done.
NCS groundwater flow and transport model, version 1, July 2013	Groundwater levels needs to be monitored and a time series data set compiled.	In progress – part of monitoring programme.
	Information on the vertical gradients existing in the aquifers needs to be generated.	In progress – specific depth sampling and groundwater characterisation forms part of the monitoring programme.
Tsumeb Water Supply and Smelter Studies	A water balance needs to be developed for the smelter and its interaction with the	In Progress.

Report	Recommendation	Action taken
Phase 4: smelter sinkhole risk and contaminant plume mapping, draft report 1, version 1, December 2014	aquifer.	
	Drilling and geological mapping to be done to confirm the lineament positions, depth of weathering and geometry of Karst cavities.	To be further investigated in future.
	Prevention of localised groundwater ingress near built structures.	Part of the surface water infrastructure upgrade plan for next few years. Initial work to commence in Q4 2016 / Q1 2017.
	Detailed monitoring of groundwater quality and levels.	Done.
	Lining of the return water dam with an impermeable liner.	Part of the surface water infrastructure upgrade plan for next few years.
	Detailed hydrocensus to be undertaken on all boreholes, including those on surrounding farms.	Done.
	Drilling of extra monitoring boreholes about 500 m to 1,000 m to the north of the site boundary.	Additional boreholes planned for 2017. Most critical ones still to be identified.
	Aquifer test to be undertaken on boreholes to the north of the site.	To be further investigated in the near future.
	Borehole water level time series data to be collected.	Done.
	Additional characterisation of the aquifer to identify and quantify the existence of vertical heads and different flow zones.	In progress – specific depth sampling and groundwater characterisation forms part of the monitoring programme.
	Fluid electrical conductivity logging of boreholes should be done to identify flow zones and understand the vertical properties	Done.

Report	Recommendation	Action taken
	of the aquifer.	
	Geochemical characterisation of the slag piles, calcine heaps, and tailings should be done to calculate contamination loads to the aquifer.	Done.
	Drilling boreholes into geophysical anomalies and pump testing of these.	To be further investigated in the near future.
Tsumeb Smelter Groundwater Model Update, Report 1, 04 March 2016	Selenium and molybdenum to form part of constituents being analysed for in future water samples from off-site boreholes.	To be included in future monitoring programmes.
	Further leach tests to be done in leach columns to determine the saturation point for the level of contamination that would lead to saturation of the adsorption/precipitation matrix.	To be further investigated in the near future.
	Drilling of monitoring boreholes to the north of the site.	Additional boreholes planned for 2017. Most critical ones still to be identified.
	More frequent sampling of boreholes on privately owned farms.	In progress – to be included in the 2017 monitoring programme.
	Redox potential for in situ aquifer conditions should be evaluated.	In progress – specific depth sampling and groundwater characterisation forms part of the monitoring programme.
	Generate vertical gradient information for the aquifer.	In progress – specific depth sampling and groundwater characterisation forms part of the monitoring programme.
	Implement bioremediation measures for arsenic removal.	Terms of reference for a study into bioremediation has been developed. ToR to

Report	Recommendation	Action taken
		be sent to market soon for tender purposes.
	Pump boreholes Slag1 to Slag 4 as well as scavenger wells to retard the arsenic plume migration.	Terms of reference for a study into finding a method for arsenic plume migration retardation has been developed. ToR to be sent to market soon for tender purposes.
Memo: Sampling Frequency and Constituents analysed, February 2016	Use current sampling methods monthly for twelve months to build baseline data and then re-evaluate future sampling programmes.	Done.
	Samples should be analysed for the constituents listed in Section 3.3.6.	Being done.
	An alternative laboratory should be used in future due to suspect analyses results being received from the current laboratory.	In progress – proposals received, and being evaluated.
	Borehole “Waste Up 1” needs to be re-drilled.	Additional boreholes planned for 2017. Most critical ones to be identified – may or may not include “Waste Up 1”.

The following is recommended to be part of the EMP:

- Additional boreholes should be drilled to the north of the site to better detect the arsenic pollution plume migration**Error! Reference source not found.**;
- Gather all data available from DMPT, GROWAS and SLR databases for the area;
- The currently predicted movement of the arsenic plume needs to be re-evaluated, taking into consideration the groundwater quality data from the TGWS.
- Rest water level data should be collected by monitoring 3 times a year in all boreholes;
- Sampling of boreholes used for irrigation and water supply;
- Determine vertical and horizontal gradients in the aquifer system;
- Implementation of the planned project for identifying major sources of groundwater pollution and implementing the clean-up and remediation of these sources over the DPMT site, for which a draft scope of work is already in place;
- Compile all data / results from above into a comprehensive new groundwater model based on the existing regional model done 2003;
- Develop and update a dynamic water balance model to integrate into the future groundwater model updates.

4 DUNDEE SMELTER EXPANSION SURFACE WATER STUDY

4.1 SCOPE OF WORK

The initial proposal included making recommendations for flood protection measures, with the inclusion of peak flow and flood line calculations using a hydraulic flood modelling package. Additionally a study to investigate and delineate clean (non-contact) and dirty (contact) water catchments would have been undertaken as part of the storm water management plan. However, once it was discovered that DPMT intends to use the Aurecon reports which cover storm water assessment and storm water management, these aspects of the proposal became redundant and a revised surface water Terms of Reference was submitted to the Client.

The Aurecon report complies with EBRD PR4 Health and Safety, Section 31 (Natural hazards), which stipulates "*The client will identify and assess the potential impacts and risks caused by natural hazards, such as earthquakes, landslides or floods as these relate to the project.*"

4.2 REGIONAL HYDROLOGY

The study area is located on the eastern side of the Etosha Basin catchment, which is an inland drainage system where runoff flows into the Etosha Pan where it then evaporates. The area around Tsumeb is predominantly karstic, which means that it is formed from the dissolution of soluble base rock (mainly dolomite and limestone in this area) which is characterised by underground drainage systems with sink holes and caves. Due to the geology of the area, there is no well-defined drainage pattern in the Tsumeb-Grootfontein area, but rather many small individual drainage systems, dependant on the local geology.

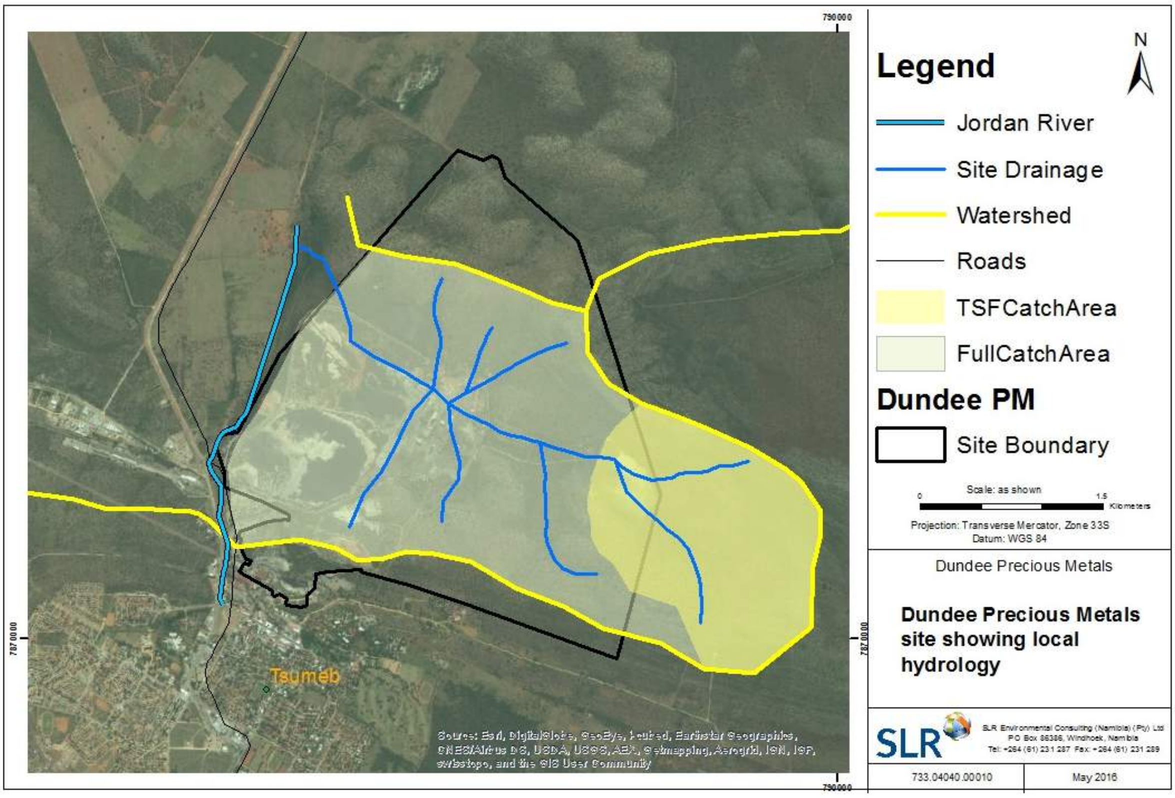


FIGURE 22: SMELTER SITE SHOWING LOCAL HYDROLOGY

4.3 LOCAL HYDROLOGY

SRTM (Shuttle Radar Topography Mission) data from NASA was used to compile a ground elevation map for the study area in conjunction with the local 1:250 000 topographical map (Map 1916 Tsumeb). From this elevation data combined with satellite images, the local catchment was identified which flows in a north westerly direction as shown in Figure 22. The catchment was divided up into an upper section (which included the old eastern Tailings Storage Facility (TSF) dam) covering an area of approximately 2.85 km^2 and the lower catchment below the TSF dam, which includes the main smelter and current western TSF areas, covering an area of 6.88 km^2, giving a total catchment area at the outlet on the border of the site boundary of 9.73 km^2. To the west of the site is a drainage line (locally known as the Jordan River), which has its catchment area in the townlands of Tsumeb, flowing in a northerly direction along the western boundary of the site and then continuing off to the north where it reportedly disappears into the ground. The Jordan River is not a natural water course, relying on runoff from the central business area and the north eastern part of Tsumeb, but typically has only a low flow or is temporarily dry if there is no rainfall. There is some indication that a portion of the water pumped from Shaft 1 reaches the Jordan River, but this is not confirmed.

Within the lower catchment area are two small dams (Dam 10 [also called No. 10 Gate Dam] which contains decant water from the tailings dam plus return process water and Railway Dam which contains overflow from Dam 10), see Figure 23.

It should be noted that there is a southern portion of the site which is not included in the main catchment, being south of the catchment divide (as shown in Figure 22), which drains in a south westerly direction into the Jordan River. Although the smelter expansion is in the main catchment, there is some remnant industrial infrastructure located in this portion (concentrator, lead furnace area, open pits) which may require remediation before site closure, to ensure that no groundwater or surface water contamination can take place from these areas towards the main residential and commercial area of Tsumeb.

4.4 PEAK FLOW ESTIMATION FOR LOCAL RUNOFF

No peak flows have been calculated for local runoff, as this information has already been generated in the Aurecon reports of 2013 (Storm Water Assessment Study and Storm Water Management Report).

4.5 SURFACE WATER QUALITY

No historical surface water sample programme has been undertaken at site, but a monitoring programme is currently being set up which should start to provide baseline data for the site. It is recommended that additional water samples should be collected from the drainage lines that run through the main site (if not part of the routine sampling schedule) after any significant rainfall event, to collect additional data for the site surface water quality, to provide information on the quality of storm runoff water at the site which would be collected in the planned pollution control dams (PCD's).

Surface water samples were collected in October 2015 by Groundwater Consulting Services at four locations within the site and one just outside the site at the Jordan River road crossing (see Figure 23). Samples within the site were collected at the Railway Dam and Dam 10 (both open water surfaces) as well as from Large Reservoir and Small Reservoir (concrete elevated reservoirs) located on the southern watershed. The water which supplies the Large Reservoir is municipal water pumped from municipal boreholes to the south of Tsumeb, while the water supply to the Small Reservoir is raw water pumped from Shaft 1. Technically the samples from the Large and Small Reservoirs are classified as groundwater, having been pumped from boreholes. An analysis of the results from this sampling can be found in Appendix 3.

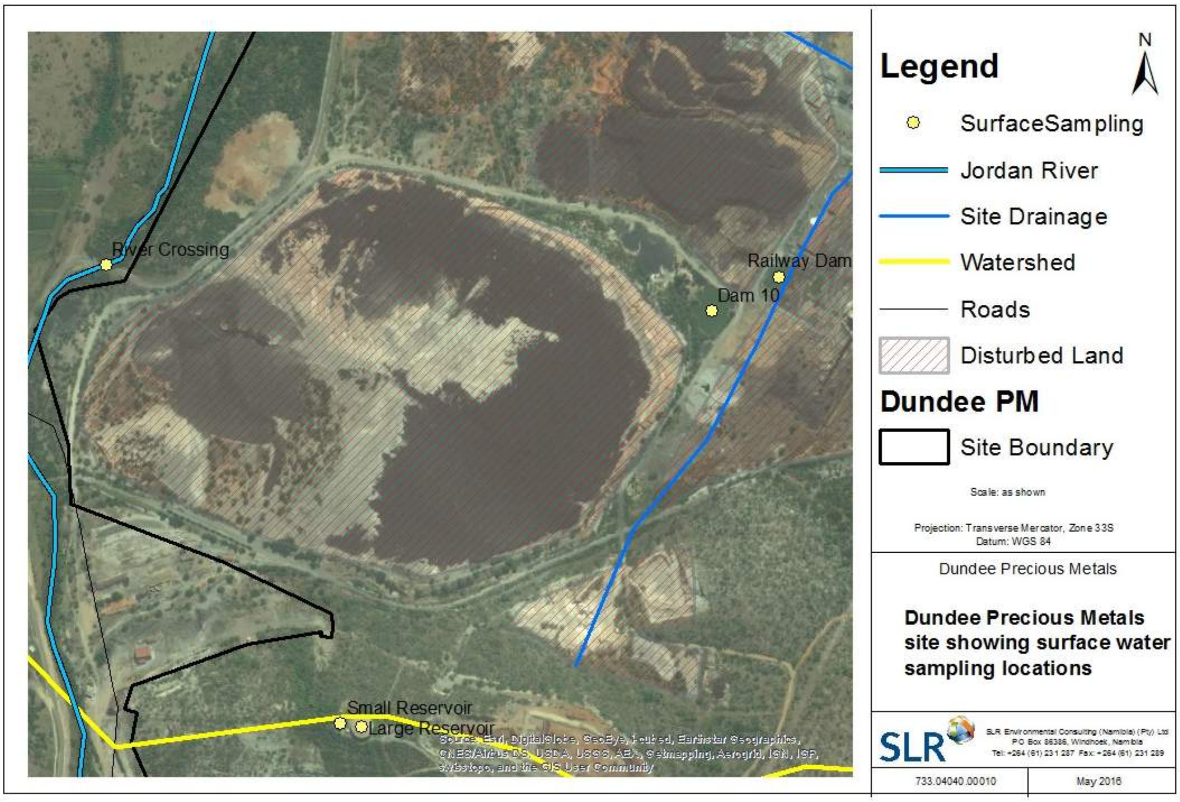


FIGURE 23: LOCAL SURFACE WATER SAMPLING LOCATIONS

It can be seen from Figure 24 that the arsenic levels in all the surface water samples except for the Municipal BH water are above acceptable guideline levels for human consumption, but even the water quality from the Municipal boreholes is only Groups C (low health risk).

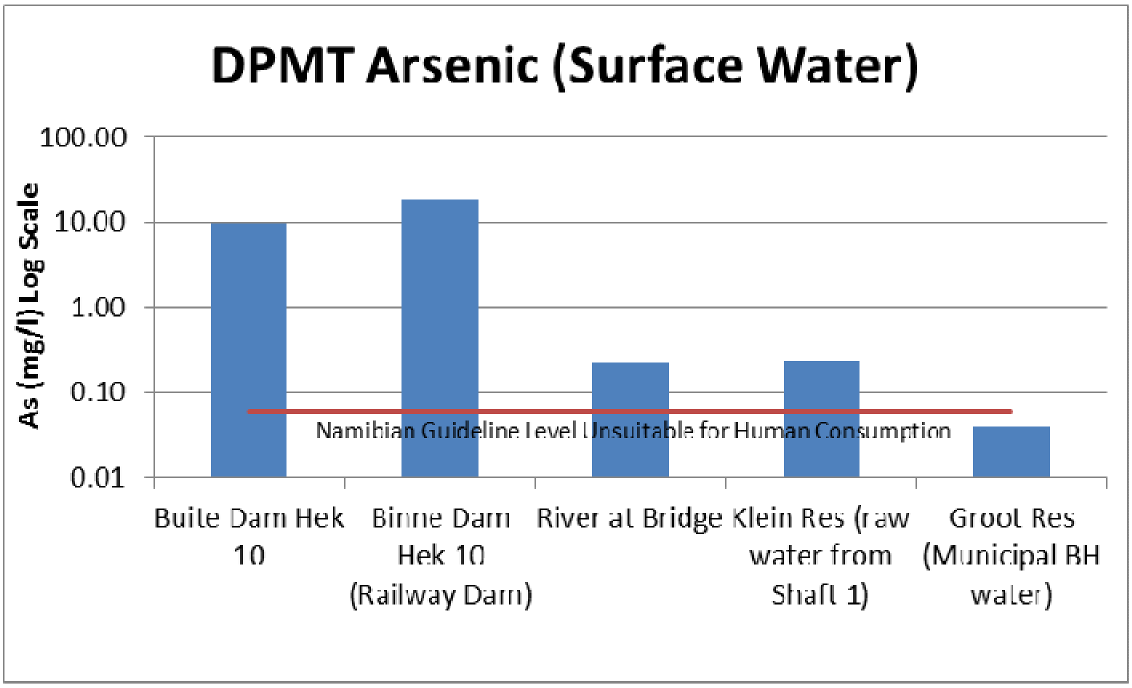


FIGURE 24: ARSENIC RESULTS FROM SURFACE WATER SAMPLING OCTOBER 2015

In June 2016 DPMT collected five water samples from the Jordan River, starting upstream of the smelter site (towards the town) and sampling at points along the boundary of DPMT with the final sample being taken downstream of the smelter site (see Figure 25). Some of these sites are similar to the surface water monitoring sites recommended in the 2013 Golder EMP document.

An analysis of the results from this sampling indicates that it is likely that there are a number of inflow points along the Jordan River, as the water quality changes quite considerably between the sampling sites, (see Appendix 4). The most significant changes occur between sampling point SW1 and SW2, with strong increases in many of the measured parameters. There appears to be another inflow after SW2, as many parameters at SW3 have decreased from the elevated levels at SW2. It should be noted that sampling sites SW 1 and SW2 are upstream of the main part of the DPMT site, but are close to the historic Tsumeb Mine area. After SW3 many parameter levels stabilise somewhat, or increase slightly. This analysis is carried out on a single set of results (excluding the additional SW4 2015 sample), so further data should be collected before undertaking a more detailed analysis of this surface water system. It should also be noted that Tsumeb Municipality discharges some effluent from the local sewage plant (after the maturation ponds) into the environment, so this will probably be an additional input to the Jordan River somewhere around site SW4, but this should be confirmed by a site investigation. Water samples are collected from this discharge by the

Municipality (for discharge permitting purposes), so this data should be included when analysis of surface water samples is undertaken in the future.

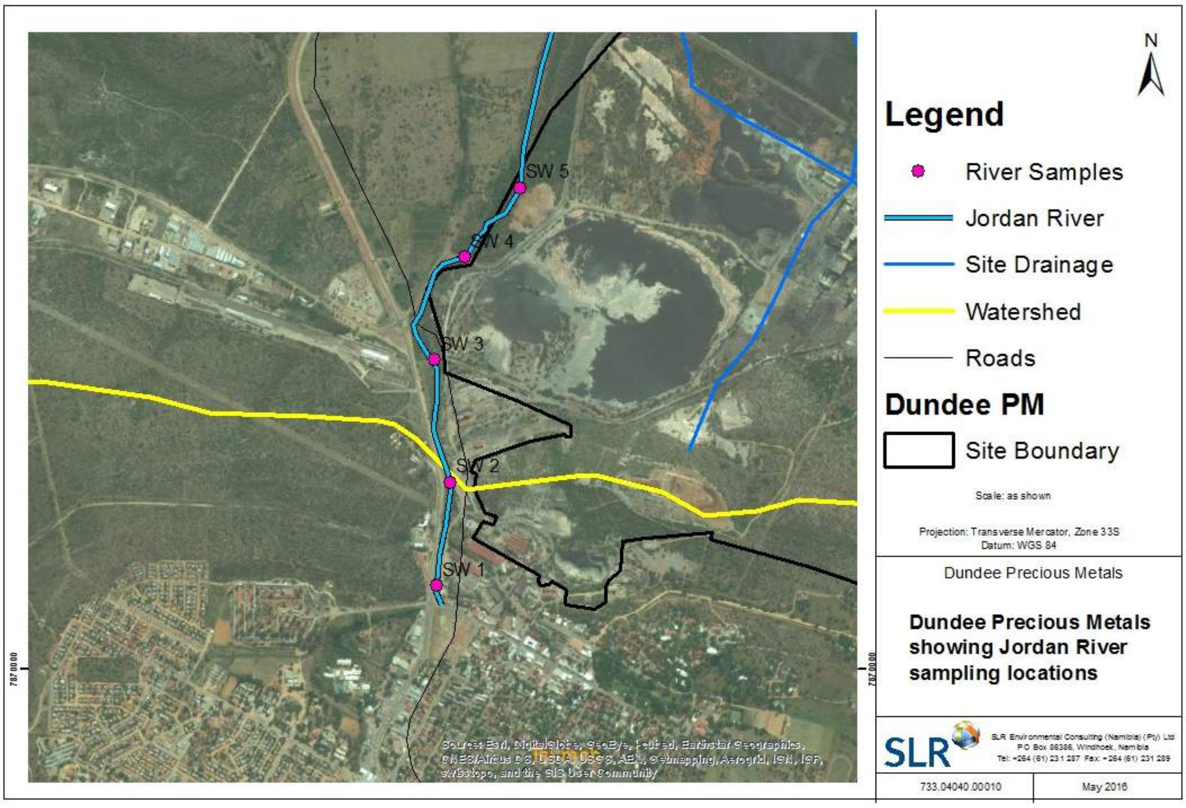


FIGURE 25: JORDAN RIVER SAMPLING LOCATIONS

It is recommended that the sampling of Dam 10 and Railway Dam is included in subsequent surface water sampling with the five Jordan River sites, to collect data both on-site and off-site. A water sample should also be collected from the Small Reservoir during the groundwater sampling, to monitor the Shaft 1 water quality. A new sampling site should possibly be added on the Jordan River downstream of SW5 at a point beyond where the main drainage line from the site enters the Jordan River, to enable monitoring of discharge from the DPMT site.

4.6 Review of Storm Water Management

Two storm water management reports were submitted to the Client by Aurecon in 2013. The first Aurecon report (September 2013) focused on the condition assessment and capacity of the storm water network, while the second report (October 2013) investigated possible drainage solutions to deal with the storm water problems experienced on site.

It is understood that the Client plans to start to implement parts of this storm water plan in a phased approach over the next few years (see Table 6). The Aurecon storm water plan upgrades the existing storm water drainage to a gravity system and includes a re-design of the on-site open and concrete lined channels, realignment of concrete hard stands and the construction of silt traps and pollution control dams (PCD's) for the containment of polluted runoff. It divides the catchment area into the "upper" eastern non-contact (clean) water runoff, which would use a diversion berm to route the water to the north around the main smelter area (Figure 26), (significantly reducing the flooding within the plant), and the "lower" contact (dirty) water runoff from the main smelter site and associated catchment, which will be collected by the gravity flow system (Figure 27) and drain in a north westerly direction into a number of PCD's (maximum of three with the actual number to depend on available space within the plant area, but one large single PCD is the best option if available space can be found). It is understood that the Client has decided to construct two PCD's adjacent to each other (to spread the capital expenditure), as well as to line Dam 10 after the first PCD is commissioned.

It should be noted that the upper catchment being categorised as non-contact assumes rehabilitation of the old eastern TSF in this catchment as well as the historical slag area.

Rehabilitation of the old eastern TSF in the upper catchment should include a dam basin survey to calculate the storage capacity of the old eastern TSF, as well as catchment calculations to provide estimated return interval storm volumes likely to be captured in the dam. In small return period storms the dam should have capacity to collect all runoff produced from the catchment and then contain this water allowing evaporation and infiltration to deplete the stored water. The relevant South African regulations (Regulation No. GN 704 of the National Water Act (1998)) for pollution control dams (PCD) stipulate that a PCD must only spill on average once in 50 years, which would be a desired design criteria for this site (as Namibia does not have specific legislation in place regulating storm water management). From the previously mentioned survey and calculations the dam volume and storm volumes would show whether the old TSF would need to be modified to contain storm runoff, such that it would only spill after the 1:50 year design storm.

Rehabilitation of the historical slag area should be undertaken on the eastern side along the main drainage line running south, as well as the southern edge along the diversion channel, to prevent contact water from the historical slag area flowing into the proposed non-contact water system discussed below.

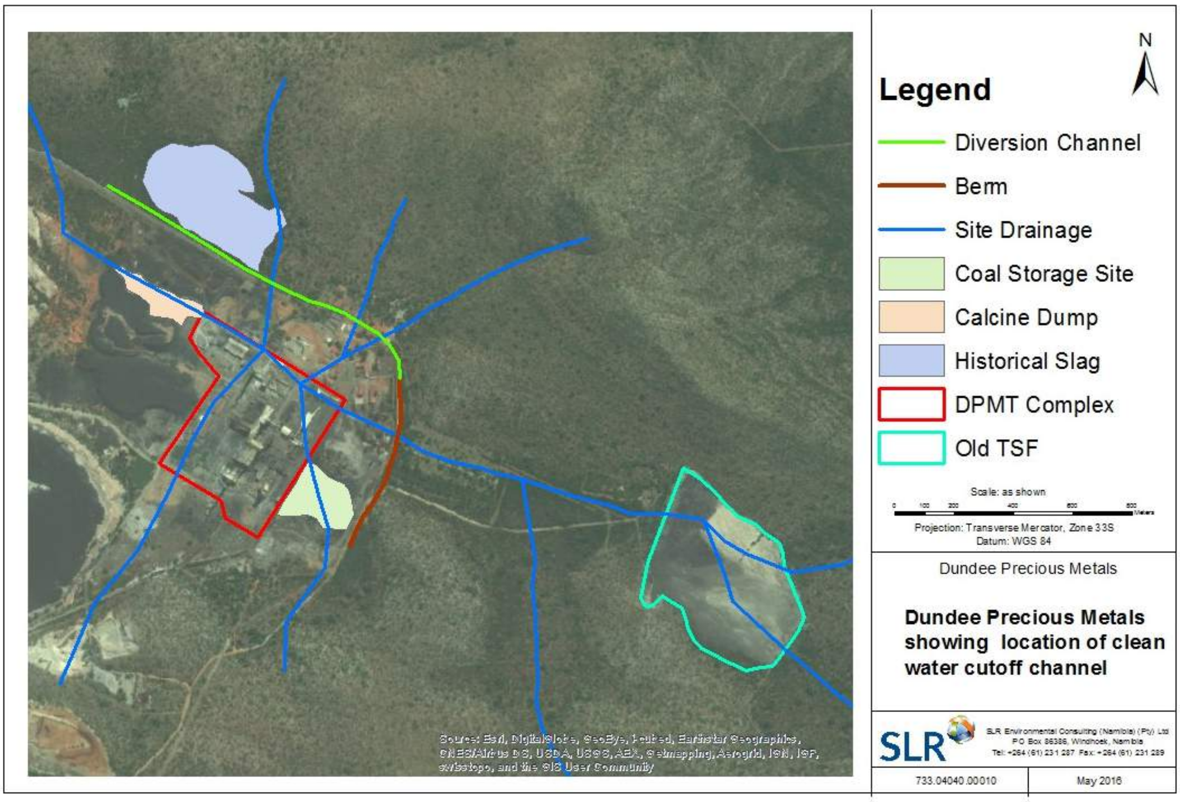


FIGURE 26 : PROPOSED CLEAN WATER CUTOFF CHANNEL (from Aurecon 2013 Report)

FIGURE 27 : PLANNED STORM WATER SYSTEM (from Aurecon 2013 Report)

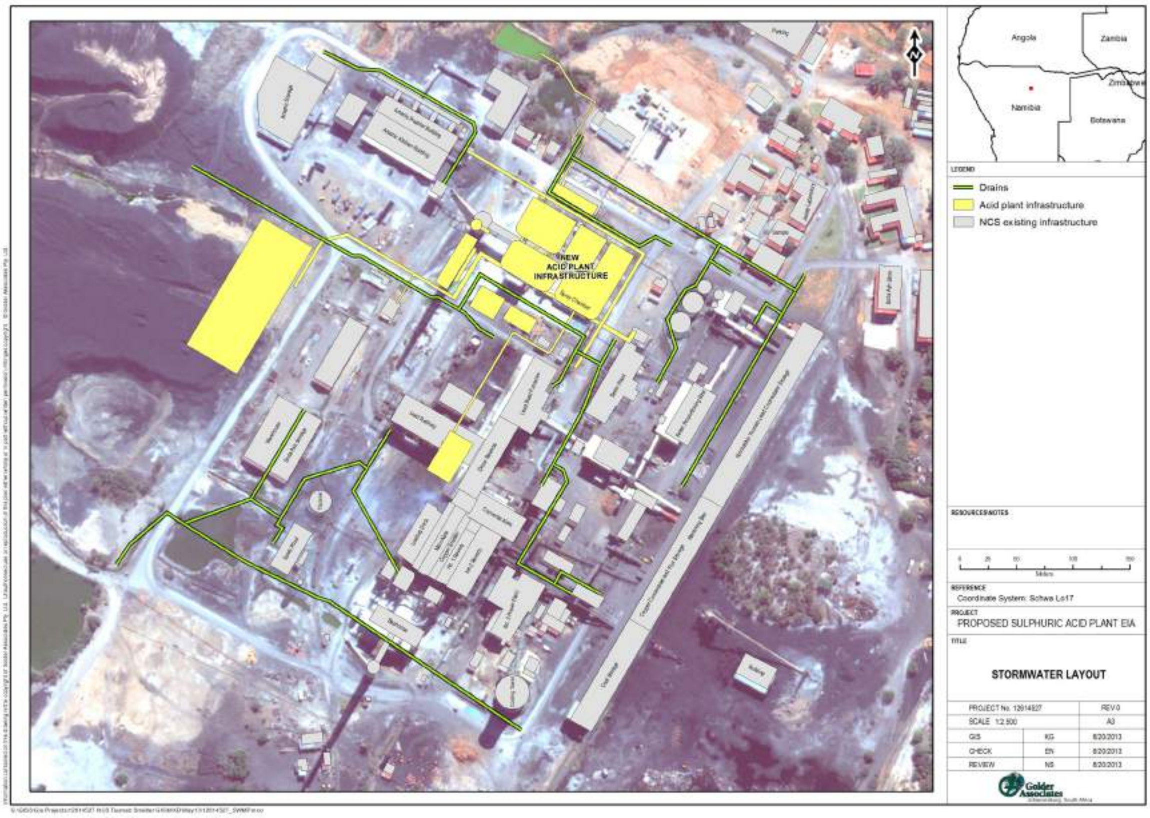


FIGURE 28 : CURRENT STORMWATER LAYOUT (from Golder Associates ESIA Report 2013)

The current storm water drainage comprises two main drainage pipelines through the plant area which end in sumps, from where the runoff is pumped to various points inside the plant (see Figure 28). Problems have been experienced with silting of the storm water system and some of the infrastructure is inadequate for the generated runoff, resulting in ponding of runoff at a number of identified sites around the plant after storm events (see Figure 29).

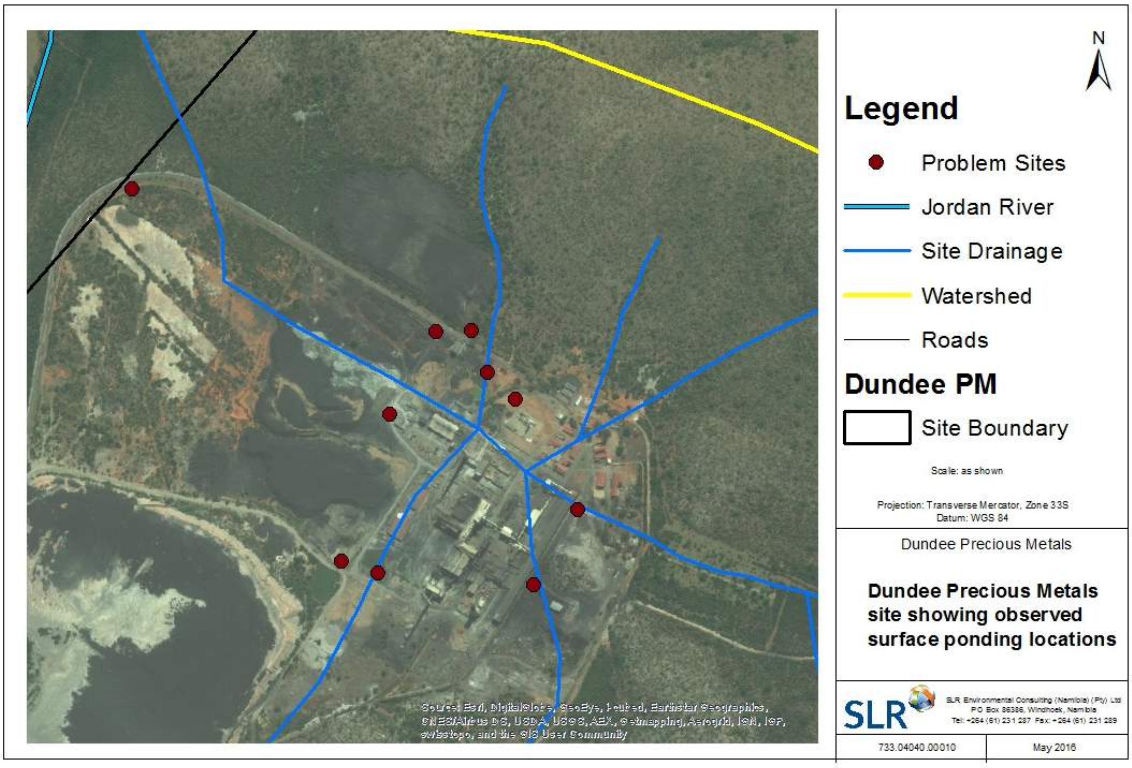


FIGURE 29: LOCAL STORM WATER PONDING LOCATIONS (from Aurecon 2013 Report)

The surface water impact assessment has therefore proceeded assuming that the new storm water infrastructure mentioned above and suitable management procedures will be in place in the medium term, and no further assessment of storm water will be undertaken in this current report.

However, Table 6 indicates the current status with regard to the Aurecon storm water management recommendations, which suggests that the phased approach may be only partial and spread over a number of years, which will result in an increased likelihood of storm water problems in the short-term

TABLE 6: LIST OF RECOMMENDATIONS MADE IN AURECON STORM WATER REPORT (2013)

Aurecon Storm Water Management - Options Report, 22 October 2013, Project 109185	
Storm Water Recommendation	Action Taken
1. The existing system is severely damaged and is beyond repair. This is especially the case with the major collectors. Some of the collectors also need rerouting as new infrastructure will be constructed over the current routes. It is therefore recommended that the entire system be replaced. The cost of complete replacement amounts to NAD 22.5 million without any hardstand modification and NAD 40.8 million with hardstand modification.	Some planning underway for this to be implemented in a phased approach.
2. It is recommended that the entire system be replaced (as mentioned in the item above) by a gravity system as described in the preceding sections. This will include the construction of either a series of pollution control dams or a single dam at the lowest point in the system.	Some planning underway for this to be implemented in a phased approach.
3. It is recommended that no process water and storm water systems integrate other than the return line from the pollution control dam.	Some planning underway for this to be implemented in a phased approach.
4. Clean water separation must be achieved through a diversion berm and channel to the east of the plant. This will prevent flooding of the plant during excessive storm events and will minimise contamination of the Jordan River with arsenic laden runoff.	Planned to be constructed as part of the phased storm water management project.
5. The filter plant must be completely bunded with no overflow to the storm water system. The filter plant has been identified as the major contributor to siltation in the northern drainage spine.	Some planning underway for this to be implemented in a phased approach.
6. It is recommended that all pollution control dams, including the existing No 10 Dam be HDPE lined to prevent any infiltration.	Planned to be undertaken when PCD phase is implemented.
7. It is recommended that an additional study, investigating phytoremediation measures to control dust, be launched.	Ongoing, nursery completed and study about to start.
8. It is recommended that Scenario One for the dams and Option One for the total system upgrade be approved for final design.	Some planning underway for this to be implemented in a phased approach.

4.7 REVIEW OF SITE WATER BALANCE STUDIES

4.7.1 GENERAL

A number of reports have been produced which include some sort of water balance as part of the study or have values for water demand for certain infrastructure.

The Golder EIA Report (2013) quotes demand figures for raw water for process use of 225 m^3/h for the Reverse Osmosis Plant, 8 m^3/h for the Effluent Treatment Plant, 5 m^3/h for the CV Filter and 12 m^3/h for the Gas Cleaning Process, plus cooling water demand for convertor hoods and convertor blower of 795 m^3/h (for a single convertor). The sulphuric acid plant is quoted as requiring 60 m^3/h of raw water and 12 m^3/h of potable water.

The Worley Parsons Smelter Expansion PFS (2015) quotes the current raw water pumping capacity as 300 m^3/h (from Shaft 1), which would need to be upgraded to approximately 400 m^3/h for the increased processing, but mentioned that the current raw water demand is not clearly identified and further investigations should be carried out.

From discussions with the Client is appears that a dynamic water balance is being completed by Golder, which should be finalised in the near future, so no detailed calculations for the water balance situation will be made here.

The EBRD PR3 Section 18 notes that *"For projects with a high water demand (greater than 5,000 m^3/day), the following must be applied:*

- *a detailed water balance must be developed, maintained and reported annually to the EBRD".*

It is unclear what the current daily water demand is running at, but the Golder dynamic water balance will provide an initial means to comply with this EBRD requirement.

4.7.2 PROCESS WATER

Aurecon produced a number of reports in 2013 including "Process Water Options Analysis Report" and "Process Water Assessment Study" which are the results of three weeks spent on site checking the process water systems. The Analysis Report gives a breakdown of the planned main process water streams on the site as follows;

- The slag mill will use raw water
- The furnace Evaporative Cooling Chambers (ECC) will use low-arsenic reclaim water (from the filter plant)
- The oxygen plants will use a mixture of raw and domestic water
- The Water Treatment Works (WTW) will use a mixture of raw and domestic water

- Reclaim water from blowdown and WTW wastes are routed to the filter plant reclaim dam
- Filtrate from the filter plant is routed to the reclaim dam at the filter plant
- The Ausmelt and Sulphuric Acid Plant (SAP) cooling circuits will use Reverse Osmosis (RO) water from the respective WTWs
- Converter furnace heat exchangers, and compressors at the power plant and the Ausmelt cold-loop will use softened water from the existing WTW
- The SAP Effluent Treatment Plant (ETP) will make use of low-arsenic reclaim water from the filter plant and produce an arsenic-rich effluent to be routed to the No. 10 dam.
- Granulation pits wouldl use high-arsenic reclaim water sourced from the No. 10 dam, (but DPMT is currently using slow cooling instead of granulation).
- Storm water reports to the filter plant reclaim water dam and the slag mill.

The Assessment Study estimated that the average raw water demand for the site is 123 m^3/h (which will have increased significantly with the construction of the sulphuric acid plant and will further increase with the planned smelter expansion), with an estimated 4 m^3/h domestic water also being used. The overall assessment for the water balance indicates that more than 67 % of the water is lost to evaporation in the various processing units and from the tailings dams, 31 % is lost to infiltration from dams and spraying and the remaining 2 % is discharged from the site as wastewater effluent. (Currently only sewage water effluent is sent to the reed beds, where it should be added to the evaporation and infiltration values in the water balance, if these beds do not discharge off-site).

4.7.3 WATER BALANCE CONCLUSIONS

The various water supplies to the site originate mainly with groundwater abstraction (supplying raw water from Shaft 1 and some additional water from recovery boreholes) and a small domestic water supply from Tsumeb Municipality, plus occasional small additions from storm water after rainfall events. A small proportion of the water supplied to site is then discharged as wastewater effluent. The supplies to the site can then be further divided into cooling (or softened) water, boiler feed (or RO) water and reclaim water streams indicating that the water balance for the site is a complicated system with many interactions and possible combinations for water consumption. The raw water supply to the site is predominately used at the sulphuric acid plant, the oxygen plant and the water treatment works (where it is treated to supply cooling and boiler feed water). The slag mill receives water from the reclaim dam and No 10 dam. The current water use is being modified as additional infrastructure is added, so it is recommended that the dynamic water balance being produced is regularly updated when changes to the plant and operations take place. This dynamic water balance should also be revised if additional groundwater studies provide additional data, as the currently used groundwater values will provide a significant input to the balance. Changes to these inputs may significantly affect the balance streams and the possibilities for the use of various water qualities for the different processes, such that the most efficient re-use of site water may change with new data. Once a detailed water balance has been completed, this will form the basis for future abstraction and discharge permit applications.

4.8 ENVIRONMENTAL IMPACTS FOR SURFACE WATER

The main likely surface water environmental impacts at the DPMT site will be from pollution generated from the runoff generated within the main site, or to a smaller extent from any spillage from the old TSF dam (located upstream to the east of the main site), in the event of a significant rainfall event, plus the wastewater effluent discharge. An additional smaller surface water impact is generated from the wastewater effluent discharge continually sent to the reed beds. However, for the purpose of this study, only additional polluted runoff generated as a result of the smelter expansion will be investigated for the impact assessment.

Figure 30 shows the main surface water related site infrastructure outside of the plant area, which shows that there are a number of areas where the surface drainage is in contact with sites of concern. The main areas where storm water could be a problem for the natural surface drainage are the coal storage area, the eastern edge of the historical slag area and the calcine dump. However, with the exception of the historical slag all the others are within the main plant area and will be addressed by the storm water management plan (discussed previously).

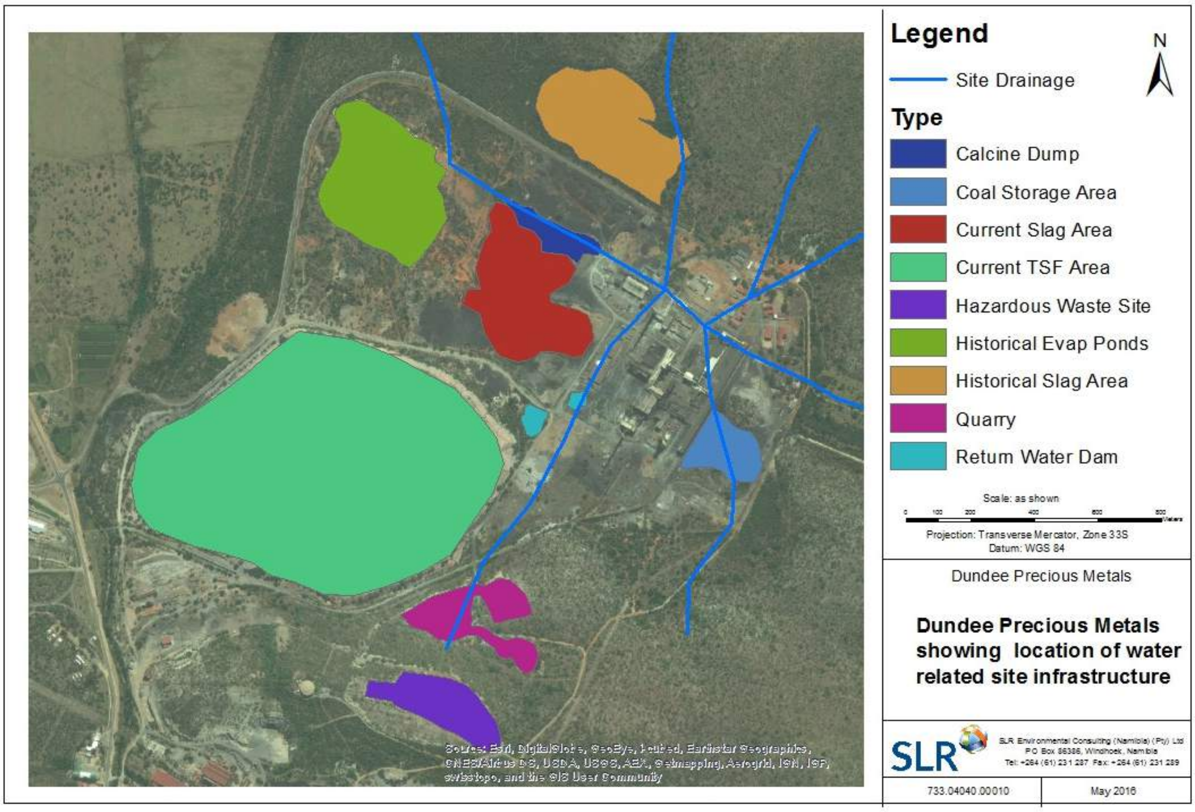


FIGURE 30: LOCATION OF SITE WATER RELATED INFRASTRUCTURE

5 GROUND- AND SURFACE WATER IMPACT ASSESSMENT

Based on the review of available data, an assessment of the cumulative potential environmental impacts that the expansion plans for the Dundee Smelter would have on groundwater and surface water have been identified, building on previous impact assessments for the site prior to the smelter expansion.

A review of previous impact assessments was made by searching through previous Environmental Impact Assessment (EIA) and Scoping Reports, which were the following;

- 2011 Environmental Assessment for the Tsumeb Smelter by Synergistics Environmental Services, (no impact assessment was included, but groundwater protection was addressed with objectives for the new tailings dam to be rehabilitated, an additional borehole to the north of the smelter operations and quarterly groundwater monitoring with analysis by an independent laboratory in the EMP section. No surface water objectives mentioned);
- 2013 ESIA for New Sulphuric Acid Plant, Tsumeb by Golder Associates, (see tables below)

TABLE 7: SUMMARY OF GROUNDWATER IMPACTS FROM GOLDER ESIA 2013

Groundwater Impacts		
Phase	Impact	Consequence
Construction Phase	Hydrocarbon spills / waste generation	Moderate
	Sanitary waste discharge	Low
Operations Phase	Spillage of contaminants	Moderate
	Process water management	High
	Sulphur dioxide emissions to atmosphere	+ High
Decommissioning Phase	Chemical spills during decommissioning	Moderate
	Temporary storage of contaminated soil / waste	Moderate

TABLE 8: SUMMARY OF SURFACE WATER IMPACTS FROM GOLDER ESIA 2013

Surface Water Impacts		
Phase	Impact	Consequence
Construction Phase	Increased soil erosion and runoff	Moderate
	Contamination from hydrocarbon spillage	Moderate
Operations Phase	Leakage / spillage from sulphuric acid storage	Moderate
	Contamination from weak acid effluent generated	Moderate
Decommissioning Phase	Contamination from solid waste generated from acid plant, while stored at hazardous waste facilities	Moderate

Additionally, Environmental Management Plans (EMP) and Scoping Reports for additional work at the site were reviewed to gather a complete picture of previous assessments.

- 2014 Scoping Report for the 11kV Power Line for DPMT, by SLR, (no specific groundwater or surface water impacts were identified outside of the generic waste management and hydrocarbon spillages during the construction phase, which were rated as medium significance for the unmitigated and low for the mitigated case);
- 2014 Scoping Report for the New Sewerage Plant, DPMT, by SLR, (the assessment for possible ground and surface water contamination from spillage or release of sewage was rated as medium without mitigation and low with mitigation measures);
- 2015 EMP for the DPMT Hazardous Waste Disposal Site, by SLR, (no impact assessment was included, but protection of groundwater and surface water environment was addressed with specific actions and schedules, including monitoring and maintenance);

In the current assessment the impact rating for each potential impact along with the criteria used to rate each impact is clearly stated. The potential impacts are rated with the assumption that no mitigation measures are applied and then again with mitigation.

The assessment criteria used for ranking these impacts is explained in Table 9 below.

TABLE 9 : CRITERIA FOR ASSESSING IMPACTS

Note: Both the criteria used to assess the impacts and the methods of determining the significance of the impacts are outlined in the following table. Part A provides the definition for determining impact consequence (combining severity, spatial scale and duration) and impact significance (the overall rating of the impact). Impact consequence and significance are determined from Part B and C. The interpretation of the impact significance is given in Part D.

PART A: DEFINITION AND CRITERIA*		
Definition of SIGNIFICANCE		**Significance = consequence x probability**
Definition of CONSEQUENCE		**Consequence is a function of severity, spatial extent and duration**
Criteria for ranking of the SEVERITY/NATURE of environmental impacts	**H**	Substantial deterioration (death, illness or injury). Recommended level will often be violated. Vigorous community action. Irreplaceable loss of resources.
	M	Moderate/ measurable deterioration (discomfort). Recommended level will occasionally be violated. Widespread complaints. Noticeable loss of resources.
	L	Minor deterioration (nuisance or minor deterioration). Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints. Limited loss of resources.
	L+	Minor improvement. Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	M+	Moderate improvement. Will be within or better than the recommended level. No observed reaction.
	H+	Substantial improvement. Will be within or better than the recommended level. Favourable publicity.
Criteria for ranking the DURATION of impacts	**L**	Quickly reversible. Less than the project life. Short term
	M	Reversible over time. Life of the project. Medium term
	H	Permanent. Beyond closure. Long term.
Criteria for ranking the SPATIAL SCALE of impacts	**L**	Localised - Within the site boundary.
	M	Fairly widespread – Beyond the site boundary. Local
	H	Widespread – Far beyond site boundary. Regional/ national

PART B: DETERMINING CONSEQUENCE					
				SEVERITY = L	
DURATION	Long term	**H**	**Medium**	**Medium**	**Medium**
	Medium term	**M**	**Low**	**Low**	**Medium**
	Short term	**L**	**Low**	**Low**	**Medium**
				SEVERITY = M	
DURATION	Long term	**H**	**Medium**	**High**	**High**
	Medium term	**M**	**Medium**	**Medium**	**High**
	Short term	**L**	**Low**	**Medium**	**Medium**
				SEVERITY = H	
DURATION	Long term	**H**	**High**	**High**	**High**
	Medium term	**M**	**Medium**	**Medium**	**High**
	Short term	**L**	**Medium**	**Medium**	**High**
			L	**M**	**H**
			Localised Within site boundary Site	Fairly widespread Beyond site boundary Local	Widespread Far beyond site boundary Regional/ national
				SPATIAL SCALE	

PART C: DETERMINING SIGNIFICANCE					
PROBABILITY (of exposure to impacts)	Definite/ Continuous	**H**	**Medium**	**Medium**	**High**
	Possible/ frequent	**M**	**Medium**	**Medium**	**High**
	Unlikely/ seldom	**L**	**Low**	**Low**	**Medium**
			L	**M**	**H**
				CONSEQUENCE	

PART D: INTERPRETATION OF SIGNIFICANCE	
Significance	**Decision guideline**
High	It would influence the decision regardless of any possible mitigation.
Medium	It should have an influence on the decision unless it is mitigated.
Low	It will not have an influence on the decision.

***H = high, M= medium and L= low and + denotes a positive impact.**

5.1 GROUNDWATER IMPACT ASSESSMENT

The groundwater impact assessment is summarised in Table 10 and in Table 11 below, focusing on potential impacts on groundwater quantity and groundwater quality respectively.

In Table 10 an assessment of the impact of the Dundee smelter expansion on groundwater quantity is undertaken and identifies a significant increase in groundwater use, which should reflect in amplification of the cone of depression caused by pumping of groundwater. The 2013 groundwater study report indicates no cone of depression existing currently, based on groundwater piezometric head as mapped at the time (GCS, 2013). The Phase Two report of the same year concludes that no changes in groundwater levels are expected (GCS, 2013 (2)). This also means no positive impact is caused by anthropogenic heads created on the tailings storage facility or any of the other dumps, leading to increased recharge. In the absence of available water balance figures and abstraction rates, it is concluded that a dynamic water balance model be developed and an upgraded groundwater model be presented to indicate the expected cone of depression based on the current abstraction rates, including the suggested abstraction from the Slag 1 – Slag 4 boreholes for remedial action.

The unmitigated scenario is assessed as medium impact, but with the recommended mitigation measures of the development of a functional water balance and improved monitoring the assessment reduces to low.

In Table 11 the assessment of impacts of the Dundee smelter expansion on groundwater quality is undertaken and shows that groundwater quality could deteriorate further. The background existing before the proposed expansion indicates that the smelter site is already impacting significantly on groundwater quality, both on and off-site, with elevated metals and sulphate concentrations being the most prominent indicators of this. The expansion would probably increase this impact, though not significantly higher than what is already in existence. Plume modelling from the 2013 and 2016 groundwater reports indicate that arsenic concentrations are elevated off-site and the plume will continue to move to the north, eventually impacting on the irrigation boreholes (GCS, 2013 and GCS, 2016). The proposed mitigation and remedial actions from these reports are not indicating any significant improvement being recorded, therefore further investigation into remedial action is needed.

The unmitigated scenario is assessed as a high impact, therefore mitigation measures are recommended to ensure that the impact is reduced.

With the proposed mitigation and remedial action being implemented the impact assessment reduces to medium.

TABLE 10 : IMPACT OF PROPOSED DUNDEE SMELTER EXPANSION ON GROUNDWATER QUANTITY

Potential impact of the planned Dundee smelter expansion on Groundwater Quantity	Unmitigated assessment						Mitigation measures	Mitigated assessment					
	Severity	Duration	Spatial Scale	Consequence	Probability	Significance		Severity	Duration	Spatial Scale	Consequence	Probability	Significance
RISK: Groundwater Levels **Severity:** Increased abstraction of groundwater for the expansion could cause a local cone of depression at the abstraction boreholes and the shaft. Indications are that no significant abstraction increase is planned and current abstraction is showing no measurable impact. **Duration:** The duration of potential for significant cones of depression forming would be for the life of the facility and causing a **low** impact. **Spatial scale:** Current maps indicates no spatial extent beyond the site boundary therefore a low influence in both the unmitigated and mitigated cases **Consequence:** Based on the above assessment the determining consequence is **low** in the unmitigated case. **Probability:** Probability of occurrence is **medium** in the unmitigated case. A radius of influence is likely but not detected due to lack of monitoring. **Significance:** Summarising the above assessment, the overall significance is rated as **medium** in the unmitigated case.	L	L	L	L	M	M	**Objective:** To reduce the impact of the cone of depression caused by groundwater abstraction **Actions:** Monitoring water levels in boreholes on site and off site (including Tsumeb Municipality and DWAF monitoring and production boreholes) to monitor possible cone of depression caused by pumping from Shaft 1. Feedback from monitoring to into the groundwater model updates. Develop a dynamic water balance model for the site to inform future remedial action. Obtain groundwater abstraction permit from Ministry of Agriculture, Water and Forestry. **Emergency situations:** None identified for the current expansion.	L	L	L	L	L	L

TABLE 11 : IMPACT OF PROPOSED DUNDEE SMELTER EXPANSION ON GROUNDWATER QUALITY

<table>
<tr><th rowspan="2">Potential impact of the planned Dundee smelter expansion on Groundwater Quality.</th><th colspan="6">Unmitigated assessment</th><th rowspan="2">Mitigation measures
Maintain efficient and effective management procedures for operating smelter.</th><th colspan="6">Mitigated assessment</th></tr>
<tr><th>Severity</th><th>Duration</th><th>Spatial Scale</th><th>Consequence</th><th>Probability</th><th>Significance</th><th>Severity</th><th>Duration</th><th>Spatial Scale</th><th>Consequence</th><th>Probability</th><th>Significance</th></tr>
<tr><td>RISK: Groundwater Pollution
Severity:
Contamination of groundwater as a result of the smelter activities will continue and is already occurring off-site. The severity is considered <u>high</u> in the unmitigated case and <u>medium</u> in the mitigated case, since the Group B water quality limit can be reached with mitigation.
Duration:
The duration of potential for pollution from polluted groundwater is for longer than the life of the project, so a <u>high</u> impact in the unmitigated state is assigned and <u>medium</u> for the mitigated state, since remedial action can reduce the period of impact.
Spatial scale:
Polluted groundwater was modelled to spread far beyond the site boundary as contamination transport is expected to follow the groundwater flow patterns, hence a <u>high</u> rating in both the unmitigated and mitigated cases
Consequence:
Based on the above assessment the determining consequence is <u>high</u> in the unmitigated case and <u>medium</u> in the mitigated case.
Probability:
Probability of occurrence is <u>high</u> in the unmitigated case and <u>medium</u> in the mitigated case.
Significance:
Summarising the above assessment, the overall significance is rated as <u>high</u> in the unmitigated case and <u>medium</u> in the mitigated case.</td><td>H</td><td>H</td><td>H</td><td>H</td><td>H</td><td>H</td><td>Objective:
Reduce the off-site spread of contaminated groundwater.
Actions:
Complete the study on sources of contamination and potential remedial action (currently only in a planning stage with scope of work developed).
Development of an improved groundwater model.
Abstraction of contaminated groundwater to reduce plume movement to the north. This will need associated water treatment and disposal.
Rehabilitation of polluting dumps in line with the closure plan recommendations.
Dispose of waste materials properly at a suitable disposal site. This would mean establishment of new sites for the extra waste volumes being generated.
Implement the Phytoremediation trials in line with the closure plan.
Drilling of additional monitoring boreholes off-site in the downgradient direction and into different geological / hydrogeological environments.
Include regional groundwater monitoring from existing farm and municipal boreholes and produce a detailed groundwater monitoring schedule.
Regular sampling at monitoring boreholes to quickly identify change in groundwater quality.
Emergency situations:
None identified for the current expansion.</td><td>M</td><td>M</td><td>M</td><td>M</td><td>M</td><td>M</td></tr>
</table>

5.2 SURFACE WATER IMPACT ASSESSMENT

The surface water impact assessment has proceeded assuming that the new storm water infrastructure and management procedures recommended by Aurecon in 2013 will be in place in the medium term, as well as rehabilitation of the (eastern) old tailings dam and historical slag areas, to ensure that runoff generated in this catchment remains non-contact.

To look at the impact of the smelter expansion, it is necessary to look at any previous surface water impact assessments for the site prior to the expansion and see whether there will be any additional impacts once the smelter expansion is completed. The earliest environmental assessment (Synergistics 2013) did not contain any specific impact assessment for surface water or any environmental management plan relating to surface water. The ESIA undertaken by Golder Associates in September 2013 for the new sulphuric acid plant concentrated on the additional infrastructure and the surface water impact assessment for the construction and operational phases only addresses issues relating to the new acid plant, while the decommissioning phase only identifies issues from acid plant waste stored at the hazardous waste facilities. The Scoping Report for the Power Line (2014) only identified Construction phase impacts, while the Scoping Report for the new Sewerage Plant (2014) only identified contamination from spillage or release of sewage. The EMP for the Hazardous Waste Disposal Site (2015) has no impact assessment, only objectives, actions and schedules as part of the EMP. From this review it appears that there is no overall site-wide surface water impact assessment, from which to add any additional impacts that the smelter expansion may cause, so this surface water impact assessment will only identify any additional impacts that the smelter expansion may introduce to the site.

The surface water impact assessment is summarised in Table 12 and Table 13.

The first table (Table 12) looks at the likely effects of the proposed Dundee smelter expansion on runoff potential. The local drainage will have infrequent surface water flow during extreme rainfall events, but the catchment is already modified with existing infrastructure around the site and the area for the expansion falls within the contact water section of the storm water management, meaning that this water will be collected and stored on site. The expansion will result in additional volumes of slag material being produced, which could require additional areas to be used for disposal of this material, so mitigation measures would include monitoring and possible upgrading of the storm water system to ensure that system capacities were able to still handle any additional contact runoff generated. Therefore the expansion will have no change to the current situation regarding runoff potential, (assuming that the storm water system has not been spilling into the Jordan River after previous extreme rainfall events).

There are no identified downstream users of surface water, between the site and the Jordan River (which has limited flow for a short distance downstream), such that any small reduction in the ephemeral runoff would not impact any downstream surface water users. The planned storm water management measures outlined by Aurecon include a clean (non-contact) water diversion channel around the northern edge of the main smelter site, to channel clean runoff away from the smelter site and towards the Jordan River. This measure will actually improve the runoff from the site, as less water will flow into the smelter area and be retained in the dirty (contact) water system at the site.

The unmitigated scenario is assessed as low impact, and with the recommended mitigation measures of reviewing and possible subsequent upgrading of the storm water system with reference to additional slag volumes, the impact remains low.

The second table (Table 13) looks at the likely effects of the proposed Dundee smelter expansion on surface water quality. The main factors which would affect the water quality are the chemicals which are stored and used on the site and waste material from the smelter, as well as fuels and oils from industrial equipment.

The unmitigated impact was assessed assuming that the proposed storm water management system has been completed. With this in place, there should be only a small likelihood of any contact water leaving the site (unmitigated case gives medium significance), but with upgrading of the storm water system to accommodate the additional smelter expansion, this would reduce to low significance. Recommended mitigation measures would consist of any additional contact storm water generated as a result of the smelter expansion being collected and channelled into lined retention ponds for re-use on site. Areas where additional smelter infrastructure is constructed, as well as the area where additional slag material is stored, should have the relevant storm water calculations re-worked to ensure that the system can handle any increased contact water runoff capacity resulting from the changes. These mitigation measures should ensure a reduced likelihood of polluted surface water reaching the Jordan River, which is located approximately 1 km to the north of the site.

TABLE 12 : IMPACT OF PROPOSED DUNDEE SMELTER EXPANSION ON SURFACE WATER RUNOFF

Potential impact of the planned Dundee smelter expansion on Surface Water resources. Downstream Decrease in Surface Water Runoff	Unmitigated assessment						Mitigation measures No mitigation measures required	Mitigated assessment					
	Severity	**Duration**	**Spatial Scale**	**Consequence**	**Probability**	**Significance**		**Severity**	**Duration**	**Spatial Scale**	**Consequence**	**Probability**	**Significance**
RISK: Reduced Runoff **Severity:** No significant contribution to downstream runoff, so severity is **low** in the unmitigated case. **Duration:** The duration of possible reduction in potential runoff is life of the project, so **medium** impact in the unmitigated case. **Spatial scale:** Beyond the site boundary but no significant distance downstream to the Jordan River, hence **medium** influence in the unmitigated case. **Consequence:** Based on the above assessment the determining consequence is **low** in the unmitigated case. **Probability:** Probability of occurrence is **low** in the unmitigated case. **Significance:** Summarising the above assessment, the overall significance is rated as **low** in the unmitigated case.	**L**	**M**	**M**	**L**	**L**	**L**	**Objective:** Ensure any additional slag material is stored so that it does not generate additional contact runoff which could overload the storm water system. Upgrade any areas where design capacity is reached, to prevent problems **Actions:** Review storm water calculations with increased contact water from additional slag storage. **Emergency situations:** None identified	**L**	**M**	**M**	**L**	**L**	**L**

TABLE 13 : IMPACT OF PROPOSED DUNDEE SMELTER EXPANSION ON SURFACE WATER POLLUTION

Potential impact of the planned Dundee smelter expansion on Surface Water resources. **Pollution of Surface Water Runoff**	**Unmitigated assessment**						**Mitigation measures** **Review and upgrading of storm water measures in the smelter expansion area** **Maintain efficient and effective management procedures for maintenance of storm water system.**	**Mitigated assessment**					
	Severity	**Duration**	**Spatial Scale**	**Consequence**	**Probability**	**Significance**		**Severity**	**Duration**	**Spatial Scale**	**Consequence**	**Probability**	**Significance**
RISK: Surface Water Pollution **Severity:** Possible pollution transported downstream from smelter site to Jordan River. Possible deterioration especially close to site, so severity is **medium** in the unmitigated case reducing to **low** in the mitigated case. **Duration:** The duration of potential for pollution is beyond the life of the smelter site, so **medium** impact in both the unmitigated and the mitigated cases. **Spatial scale:** Beyond the site boundary possibly down to the Jordan River, but some dilution effect in Jordan River, hence **medium** influence in the both the unmitigated and the mitigated cases. **Consequence:** Based on the above assessment the determining consequence is **medium** in the unmitigated case and **low** in the mitigated case. **Probability:** Probability of occurrence is **medium** in the unmitigated case and **low** in the mitigated case. **Significance:** Summarising the above assessment, the overall significance is rated as **medium** in the unmitigated case and **low** in the mitigated case	**M**	**M**	**M**	**M**	**M**	**M**	**Objective:** Ensure any additional contact runoff from the smelter expansion does not overload the storm water system. Upgrade any areas where design capacity is reached Efficient management of site practices to ensure possible pollution sources stored and used safely. Mine closure planning to ensure site clean-up to remove or effectively contain polluting materials, to prevent future contamination of runoff from site. **Actions:** Storm water management, construction of additional infrastructure to manage contact waters around smelter expansion site if required. Effective site supervision to ensure no blocking of storm water infrastructure and efficient storage of contact water. Regular sampling of runoff water and downstream Jordan River to monitor pollution levels. Removal or containment of “problem” materials at mine closure. **Emergency situations:** None identified.	**L**	**M**	**M**	**L**	**L**	**L**

5.3 CUMULATIVE IMPACT ASSESSMENT OF PROPOSED DUNDEE SMELTER EXPANSION ON GROUND- AND SURFACE WATER RESOURCES

Summarising the above impact assessments the cumulative impacts are discussed in order to see whether the Dundee smelter expansion will adversely affect the ground- and surface water resources.

From the previous tables it can be seen that the cumulative effect of the smelter expansion at the site will result in a low impact on the groundwater quantity and surface water quantity and quality, but a high impact on the groundwater quality, resulting mainly from the historical conditions with very little additional negative impact from the smelter expansion, should the additional waste being generated be handled according to international best practice.

A major factor in the future assessment is the assumption that the surface water on site will be controlled by the planned storm water infrastructure and the implementation of the rehabilitation measures envisaged in the closure plan, which will reduce the point source for much of the current and future pollution load, but this will not have an impact on historical pollution which has already entered the groundwater system. Recommended groundwater abstraction from boreholes to the north of the smelter site (to intercept the probable arsenic plume and create a cone of depression to capture polluted groundwater) would then target the existing historical pollution to improve the overall groundwater quality situation.

6 SUMMARY AND CONCLUSIONS

The EIA for the proposed Dundee smelter expansion requires a ground- and surface water study to investigate the likely impacts that this additional infrastructure could have on the environment and for these results to be included in a cumulative site impact assessment.

Recommendations have been made to mitigate identified possible impacts which could arise from the expansion.

It is concluded that the planned smelter expansion will have a relatively small impact on the groundwater quantity, but a cumulative negative impact on the groundwater quality in the area around the project is already in existence. However, the majority of this negative impact is the result of historic pollution of the site, which was not remediated successfully, with very little additional impact resulting from the smelter expansion.

Surface water conclusions are that the planned smelter expansion will have a possible negative impact on the surface water quality (if the planned storm water system is not operated and maintained properly), but no significant reduction in the surface water volumes.

It is recommended that the groundwater and surface water sampling programmes are maintained to enable a database to be built up on water quality to enable any changes in groundwater or surface water quality to be identified.

Additional recommendations are:

- Drilling of monitoring boreholes along the suggested arsenic pollution plume to the north of the smelter site, to depths as dictated by the existing geology;
- Additional monitoring of water supply boreholes of the down-gradient groundwater users, in the path of the suggested arsenic pollution plume, but also regional farmers' and municipal monitoring and production boreholes, which could possibly be affected.
- Development of a detailed groundwater monitoring schedule including on-site quarterly and off-site (regional) biannual monitoring.
- Implementation of the planned project for identifying major sources of groundwater pollution and implementing the clean-up and remediation of these sources over the DPMT site.
- Targeted groundwater abstraction from identified recovery boreholes to the north of the smelter site, to reduce the spread of the arsenic pollution plume to the north, as well as possible increase in the number of recovery boreholes.
- Gathering all data available from DMPT, GROWAS and SLR databases;

- The currently predicted future movement of the arsenic plume needs to be re-evaluated, taking into consideration the groundwater quality data from the TGWS and planned new monitoring boreholes;
- Integrating a detailed site water balance;
- Obtain water abstraction and water discharge licenses from the responsible Line Ministry. Abstraction permit applications made in writing are processed through the Law Administration Division within the DWAF, when operations are within a declared groundwater control area or when the operations are of a certain magnitude. The groundwater related permit applications are evaluated by the Geohydrology Division which offers recommendations and defines permit conditions to be observed by the applicant in the event that the permit is awarded for a prescribed validity period. Once Geohydrology recommends an abstraction permit, the Permanent Secretary of MAWF signs the permit. Permit applications that are related to effluent discharge are evaluated by the Water and Environment Division, Directorate of Resource Management, in DWAF, which offers recommendations and defines permit conditions to be observed by the applicant in the event that the permit is awarded. Figure 31 gives a short insight of the process for effluent permit applications.

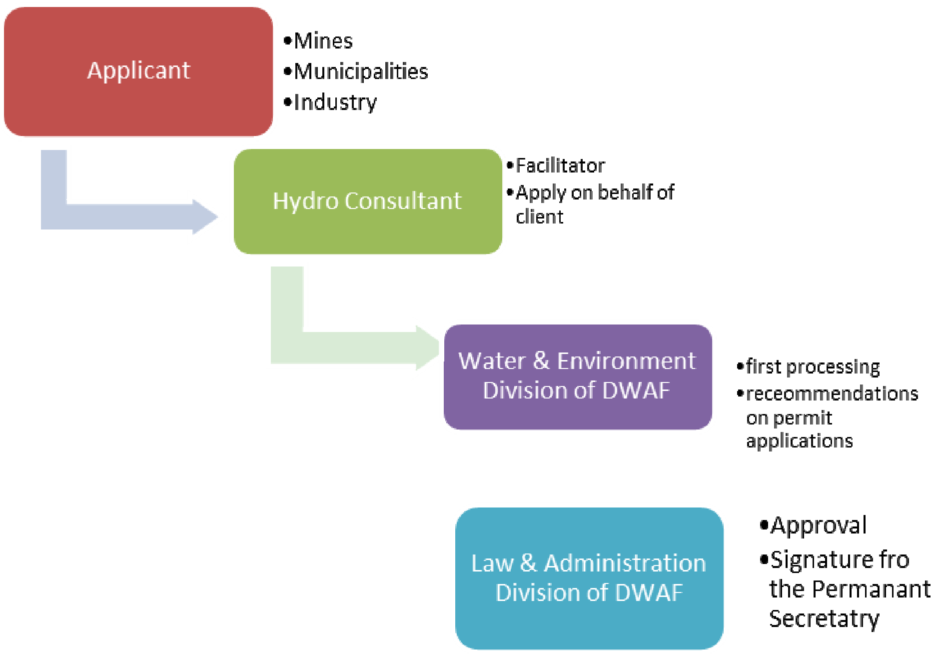


FIGURE 31: PROCESS FOR EFFLUENT PERMIT APPLICATION

- Obtain environmental clearance from MET for abstraction of groundwater for industrial purposes as part of this EIA study.

- Consider compiling all data / results from above into a comprehensive new groundwater model.

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8 APPENDICES

APPENDIX 1: WATER QUALITY GUIDELINES (DWAF, 1988)

			Namibia, Department of Water Affairs Guidelines for the evaluation of drinking-water for human consumption with regard to chemical, physical and bacteriological quality 20 October 1988			
Parameters and Expression of the results			**Group A Excellent Quality**	**Group B Good Quality**	**Group C Low Health Risk**	**Group D Unsuitable**
A. PHYSICO-CHEMICAL PARAMETERS						
Temperature	**T**	°C	-	-	-	-
Hydrogen ion concentration	**pH**	pH unit	6.0 to 9.0	5.5 to 9.5	4.0 to 11.0	4.0 to 11.0
Conductivity at 25 °C	**EC**	mS/m	150 -	300 -	400 -	400 -
Total dissolved solids	**TDS**	mg/l	-	-	-	-
Dissolved oxygen	**% O_2 saturation**	mg/l	-	-	-	-
Chlorides	**Cl**	mg/l	250	600	1300	1300
Sulphates	**SO_4**	mg/l	200	600	1200	1200
Total Hardness	$CaCO_3$	mg/l	300	650	1200	1200
Calcium	**Ca** CaCO3	mg/l mg/l	150 375	200 500	400 1000	400 1000
Magnesium	**Mg** $CaCO_3$	mg/l mg/l	70 290	100 420	200 840	200 840
Sodium	**Na**	mg/l	100	400	800	800
Potassium	**K**	mg/l	200	400	800	800
Aluminium	**Al**	µg/l	150	500	1000	1000
B. PARAMETERS CONCERNING SUBSTANCES UNDESIRABLE IN EXCESSIVE AMOUNTS						
Nitrates	**NO_3** N	mg/l mg/l	45 10	90 20	180 40	180 40
Nitrites	**NO_2**	mg/l	-	-	-	-
Ammonium	**NH_4** N	mg/l mg/l	1.5 1	2.5 2	5 4	5 4
Fluoride	**F**	mg/l mg/l	1.5 -	2.0 -	3.0 -	3.0 -
Hydrogen sulphide	**H_2S**	µg/l	100	300	600	600
Phosphorus	P_2O_5 **PO_4**	µg/l µg/l	- -	- -	- -	- -
Boron	**B**	µg/l	500	2000	4000	4000
Iron	**Fe**	µg/l	100	1000	2000	2000
Manganese	**Mn**	µg/l	50	1000	2000	2000
Copper after 12 hours in pipe	**Cu**	µg/l µg/l	500 -	1000 -	2000 -	2000 -
Zinc after 12 hours in pipe	**Zn**	µg/l µg/l	1000 -	5000 -	10000 -	10000 -
Cobalt	**Co**	µg/l	250	500	1000	1000
Barium	**Ba**	µg/l	500	1000	2000	2000
Silver	**Ag**	µg/l	20	50	100	100
C. PARAMETERS CONCERNING TOXIC SUBSTANCES						
Arsenic	**As**	µg/l	100	300	600	600
Beryllium	**Be**	µg/l	2	5	10	10
Cadmium	**Cd**	µg/l	10	20	40	40
Cyanides	**CN**	µg/l	200	300	600	600
Chromium	**Cr**	µg/l	100	200	400	400
Mercury	**Hg**	µg/l	5	10	20	20
Nickel	**Ni**	µg/l	250	500	1000	1000
Lead	**Pb**	µg/l	50	100	200	200
Antimony	**Sb**	µg/l	50	100	200	200
Selenium	**Se**	µg/l	20	50	100	100
Vanadium	**V**	µg/l	250	500	1000	1000
D. FURTHER PARAMETERS						
Bismuth	**Bi**	µg/l	250	500	1000	1000
Bromine	**Br**	µg/l	1000	3000	6000	6000
Cerium	**Ce**	µg/l	1000	2000	4000	4000
Gold	**Au**	µg/l	2	5	10	10
Iodine	**I**	µg/l	500	1000	2000	2000
Lithium	**Li**	µg/l	2500	5000	10000	10000
Tellurium	**Te**	µg/l	2	5	10	10
Thallium	**Tl**	µg/l	5	10	20	20
Tin	**Sn**	µg/l	100	200	400	400
Titanium	**Ti**	µg/l	100	500	1000	1000
Tungsten	**W**	µg/l	100	500	1000	1000
Uranium	**U**	µg/l	1000	4000	8000	8000

APPENDIX 2: MET. OFFICE RAINFALL DATA FOR TSUMEB AREA (mm)

Gaikos (Met. Office No. 1056 7174)

Gaikos 10567174	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Gaikos Annual Rainfall (mm)
1986	129	64.9	265	0	0	0	0	0	5.7	89.1	50	24.6	628.3
1987	72.3	169.8	27	27.5	0	0	1.8	0	0	13	34.7	231.5	577.6
1988	50	75.1	38.3	46.5	0	0	0	0	0	0	45	193.4	448.3
1989	77.1	195.1	20	104	0	0	0	0	0	6.5	30	36	468.7
1990	215.1	19.6	127	13.5	0	0	0	0	0	39.3	15.1	58.6	488.2
1991	148	102	63.5	0	0	0	0	0	3.8	2.7	51	171	542.0
1992	143.1	30	77.5	0.1	0	0	0	0	14	4.9	28.9	21	319.5
1993	80.3	94.8	44.3	33.5	4	0	0	0	0	45.3	65.5	49.7	417.4
1994	287.3	128.8	20	5	0	0	0	0	0	1.7	83.9	3.5	530.2
1995	30	60	74.9	0	15	2	0	0	7.5	29	27.3	25.5	271.2
1996	159.3	121.3	26.2	15.5	0	0	0	0	0	3.5	24.3	118.3	468.4
1997	241.8	124.5	88.7	10	0	0	0	0.1	48.1	44	6.5	84.6	648.3
1998	62	17.5	6	77	0	0	0	0	0	20.6	14.9	115.6	313.6
1999	112.4	37.5	98.6	0	3.5	0	0	0	12	0.8	51.8	165.6	482.2
2000	107.2	170.5	94.8	11.3	10	0	0	0	0	38.4	22.6	62	516.8
2001	36.5	86	105.5	37.9	6.3	0	0	0	50	0	47.2	15.5	384.9
2002	116.5	81.7	150.5	10.5	0	0	0	0	0	13	95	79.5	546.7
2003	73.3	76.5	39.7	0	LR	1	0	0	1	19.5	57.5	1.5	270.0
2004	132.4	75.6	97.1	197	0	0	0	0	0	66.1	31.1	31.2	630.5
2005	99.7	63	39	54.5	0	0	0	0	0	3	51.5	61.7	372.4
2006	342.5	LR	122.5	5.5	19.3	0	0	0	1.5	28.5	43.5	89.5	652.8
2007	120.5	31.5	20.5	29	0	0	0	0	0	24	63.8	79	368.3
2008	203.1	138.9	92.4	0.1	1	0	0	0	0	0	101.2	20	556.7
2009	230.4	158.5	95.7	3.5	29.3	0.4	0	0	10	23.6	23.1	1.8	576.3
2010	144	52.6	90.9	29	LR	LR	LR	LR	LR	LR	LR	49	-
2011	LR	LR	196	LR	11	0	LR	LR	LR	LR	110	LR	-
2012	180.2	143.3	87.2	6.5	0	0	0	0	0	25	63.5	54.2	559.9
2013	92	32	37.7	0	1.5	0	0	0	0	2.7		145.5	311.4
2014	16.3	215.5	126.9	51.1	LR	0	LR	0	2	30.2	112	44.8	598.8
2015	9.6	13	90.7	18.4	0	0	0	0	0.5	LR	LR	LR	-
Mean	128.0	92.1	82.1	27.1	3.7	0.1	0.1	0.0	5.6	21.3	50.0	72.6	479.6
Max	342.5	215.5	265	197	29.3	2	1.8	0.1	50	89.1	112	231.5	652.8
Median	116.5	79.1	87.95	11.3	0	0	0	0	0	19.5	47.2	56.4	488.2

Yellow highlight in last column indicates no annual rainfall value calculated due to Lost Record

Choantsas (Met. Office No. 1104 2024)

Choantsas 11042024	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Choantsas Annual Rainfall (mm)
1986	52.0	139.0	103.0	38.0	0.0	1.0	0.0	0.0	16.0	66.0	34.5	9.5	459.0
1987	30.5	97.5	38.5	25.0	1.0	0.0	6.0	0.0	0.0	9.0	17.5	101.0	326.0
1988	58.5	25.0	67.5	35.5	0.0	0.0	0.0	0.0	0.0	4.5	15.5	127.0	333.5
1989	188.5	247.0	0.0	73.5	5.0	0.0	0.0	0.0	0.0	0.5	0.0	18.0	532.5
1990	184.0	44.5	74.0	7.5	0.0	0.0	0.0	0.0	0.0	0.0	18.5	77.5	406.0
1991	187.0	134.0	35.0	0.0	0.0	0.0	0.0	0.0	0.2	19.5	55.0	116.5	547.2
1992	70.5	9.5	66.5	6.0	0.0	0.0	0.0	0.0	17.1	0.1	43.0	38.0	250.7
1993	113.0	128.5	57.5	25.0	0.0	0.0	0.0	0.0	0.0	40.0	128.5	106.5	599.0
1994	218.0	125.0	21.5	0.0	0.0	0.0	0.0	0.0	0.0	3.0	52.5	1.5	421.5
1995	9.0	52.5	44.0	0.0	29.0	4.0	0.0	0.0	3.0	0.0	22.5	130.5	294.5
1996	171.5	106.5	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.0	125.0	442.0
1997													-
1998	86.5	70.5	6.0	15.0	0.0	0.0	0.0	0.0	0.0	10.0	4.0	31.2	223.2
1999	166.0	47.5	116.0	5.0	0.0	0.0	0.0	0.0	2.0	14.5	39.5	242.6	633.1
2000	102.0	144.0	87.5	45.5	34.0	0.0	0.0	0.0	0.0	12.0	5.0	72.5	502.5
2001	56.5	207.4	52.0	133.0	0.0	0.0	0.0	0.0	86.0	0.0	42.0	35.0	611.9
2002	25.0	92.0	45.5	13.0	LR	LR	LR	LR	LR	LR	LR	LR	-
2003	71.0	102.0	16.0	9.5	0.0	0.0	0.0	0.0	0.0	60.0	81.5	54.0	394.0
2004	112.0	84.5	89.0	87.0	0.0	0.0	0.0	0.0	0.0	8.5	18.5	33.0	432.5
2005	LR	101.0	62.0	47.0	0.0	0.0	0.0	0.0	0.0	0.0	52.0	52.0	314.0
2006	176.5	230.5	78.0	0.0	0.0	0.0	0.0	0.0	0.0	40.5	68.5	31.0	625.0
2007	88.0	28.5	25.5	8.0	0.0	0.0	0.0	0.0	0.0	30.5	34.0	80.8	295.3
2008	246.0	151.0	199.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	209.0	35.7	841.2
2009	122.5	155.5	80.0	0.0	6.5	8.5	0.0	0.0	8.5	29.0	128.5	72.0	611.0
2010	LR	LR	LR	44.0	LR	LR	LR	LR	LR	LR	LR	LR	-
2011	271.0	81.0	201.5	79.5	25.0	0.0	0.0	0.0	0.0	0.2	52.0	107.5	817.7
2012	148.5	239.5	134.5	28.0	0.0	LR	LR	0.0	0.0	37.0	46.0	161.5	795.0
2013	26.5	20.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.5	159.5	258.5
2014	62.6	141.5	201.0	59.0	0.0	0.0	0.0	0.0	0.0	21.5	51.3	63.1	600.0
2015	31.5	41.0	71.0	24.5	0.0	0.0	0.0	0.0	0.0	9.5	LR	LR	-
Mean	113.9	108.8	71.5	27.9	3.7	0.5	0.2	0.0	4.9	15.4	49.3	80.1	483.3
Max	271.0	247.0	201.5	133.0	34.0	8.5	6.0	0.0	86.0	66.0	209.0	242.6	841.2
Median	102.0	101.5	64.3	15.0	0.0	0.0	0.0	0.0	0.0	9.0	40.8	72.3	450.5

Yellow highlight in last column indicates no annual rainfall value calculated due to Lost Record

Tsumeb (Met. Office No. 1055 3743) Annual Rain

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
1913									6.6	5.6	66.0	79.5	
1914	93.0	111.8	68.3	50.5	0	0	0	0.5	0	37.6	2.0	82.8	446.5
1915	192.3	166.4	3.0		0.5	0	0	0.0	16.8	0		124.2	
1916	75.4	43.9	143.3	7.1	0	0	0	0.0	0.0	15.2	102.1	159.5	546.6
1917	49.8	200.4	42.2	29.5	35.8	0	0	0.0	1.0	4.8	37.3	91.4	492.3
1918	141.0	36.3	186.2	0	0	0	0	0.0	3.8	39.9	12.4	101.1	521.0
1919	117.6	58.7	26.2	11.4	0	0	0	1.0	1.3	32.3	45.2	70.4	364.0
1920	116.8	103.6	20.1	2.8	5.8	0	0	0	0	0	166.9	24.4	440.4
1921	114.6	176.5	63.2	17.5	59.2	0	0	0	0	9.7	73.7	33.5	547.9
1922	40.1	61.2	49.0	1.0	3.0	0	0	0	0	80.5	51.8	14.2	301.0
1923	139.4	308.6	164.3	33.5	7.4	0	0	0	0	12.4	24.6	45.0	735.3
1924	52.6	92.2		0	0	0	0	0	0.5	33.5	83.6	117.3	
1925	198.6	143.3	183.4	169.2	29.2	0	0	0	0	0	56.6	44.7	825.0
1926	136.7	36.1	63.5	82.6	3.6	7.1	0	0	2.5	34.5	95.8	146.1	608.3
1927	73.4	53.1	67.8	48.0	0	0	0	0	0	29.2	49.5	51.1	372.1
1928	94.2	52.6	126.7	44.2	0	0	0	0	12.7	0.0	43.4	7.1	381.0
1929	46.5	132.3	57.7	4.3	0	0	0	0	0	41.7	77.0	13.0	372.4
1930	101.1	80.8	81.8	65.8	0	0	0	0	0	2.8	11.7	34.0	378.0
1931	122.9	136.7	128.5	25.7	0.5	0	0	0	0	18.8	111.8	94.2	639.1
1932	28.4	75.7	50.5	5.1	3.6	0	0	0	0	29.7	36.1	104.6	333.8
1933	51.6	35.3	32.3	4.6	0	0	0	0	0	4.1	63.0	130.3	321.1
1934	335.0		102.4	83.3	0.3	0	0	0	0	15.2	25.9	145.0	
1935	129.8	65.5	45.5	22.6	2.0	0	0	0	0	8.6	56.6	98.0	428.8
1936	81.0	71.9	151.9	14.2	15.2	0	0	0	0.5	1.5	10.7	70.6	417.6
1937	54.4	157.0	38.1	91.9	2.8	0	0	0	0	29.5	73.9	133.9	581.4
1938	204.0	198.6	17.3	48.8	11.7	0	0	0	0	10.4	131.8	64.8	687.3
1939	37.3	9.1	126.5	25.9	3.6	0	2.0	0	0	31.0	47.2	168.1	450.9
1940	193.8	48.0	96.3	35.8	0	0	0	0	0	6.9	15.2	133.9	529.8
1941	80.3	65.5	15.5	41.4	0	0	0	0	0.3	33.8	7.1	29.0	272.8
1942	103.9	141.5	213.4	25.4	0	0	0	0	0	58.4	11.9	119.6	674.1
1943	30.7	24.1	84.1	56.4	0	0	0	0	0	0	68.8	206.5	470.7
1944	300.7	370.6	54.1	5.1	0	0	0	0	0	25.4	30.2	63.8	849.9
1945	45.5	44.7	61.0	18.8	0	0	0	0	0	11.9	130.6		
1946	61.5	44.7	26.2	6.6	0	0	0	0	4.1	4.8	55.6	31.0	234.4
1947	204.7	213.1	68.3	29.5	0	3.3	0	0	0.5	2.8	87.1	116.1	725.4
1948	67.3	212.1	42.7	29.7	4.8	0	0	0	0	20.1	74.2	1.8	452.6
1949	54.6	53.1	124.2	5.1	0	0	0	0	0	1.0	79.2	48.3	365.5
1950	171.2	223.0	127.3	185.7	34.0	0	0	0	0	0.0	77.2	117.6	936.0
1951	24.3	107.8	81.0	63.3	44.5	0	0	0	0	52.2	25.9	131.9	530.9
1952	0.0	145.0	1.8	3.6	0	0	0	0	0	25.0	46.8	61.2	283.4
1953	134.7	181.6	56.8	29.4	18.9	0	0	0	0.6	20.8	71.4	121.2	635.4
1954	183.4	220.2	254.0	58.3	0	0	0	0	4.8	7.9	32.3	98.9	859.8
1955	149.9	98.7	45.4	56.6	0	0	0	0	0	34.5	38.9	130.9	554.9
1956	174.8	262.1	136.6	37.9	23.3	0	0	0	20.3	10.0	13.0	73.0	751.0
1957	158.4	141.0	74.8	14.9	3.1	0	0	0	0.3	40.0	47.8	96.3	576.6
1958	147.1	121.5	40.6	12.1	0	0	0	0	10.6	6.1	76.9	86.7	501.6
1959	52.8	139.2	63.4	102.3	3.3	0	0	0	0	6.6	15.5	102.3	485.4
1960	108.1	302.5	16.9	56.9	2.4	0	0	0	0	47.1	65.9	67.2	667.0
1961	74.3	134.7	133.8	31.6	20.2	5.3	0	0	0	0.5	118.7	65.9	585.0
1962	61.8	180.8	29.1	17.5	0	0	0	5.3	0	36.2	57.2	49.1	437.0
1963	140.5	47.8	124.7	48.3	0	0	0	0	0	6.1	152.6	44.0	564.0
1964	39.2	31.8	30.5	20.7	0	0	0	0.3	0	5.6	8.9	52.2	189.2
1965	80.6	87.1	97.3	54.4	0	0.5	0	0	12.7	3.5	74.4	62.2	472.7
1966	241.0	65.7	78.6	37.3	0	0	0	0	24.5	0.9	9.0	62.4	519.4
1967	207.7	124.6	128.6	32.2	0	0	0	0	2.7	14.9	184.9	122.0	817.6
1968	202.0	46.0	151.0	18.4	31.3	0	0	0	0	2.5	96.2	56.8	604.2
1969		157.2	134.0	30.8	0	0	0	0	0	20.1	88.3	9.4	
1970	129.3	74.2	19.5	23.8	0	0	0	0	0	8.8	16.1	117.5	389.2
1971	220.1	198.1	19.1	12.1	0	0	0	0	0	30.0		9.6	
1972	125.6	38.2	179.0	10.5	0	0	0	0	0	67.9	0	9.7	430.9
1973	75.8	22.6	160.1	16.9	0	0	0	0	0				
1974		167.6	73.0	61.6	0	0	0	0	0	29.4	55.5	28.0	
1975	158.0	62.3	160.5	50.5	0	0	0	0	0	0	68.2		
1976													
1977			21.5	53.6	0	0	0	0	6.0	0	83.0	73.2	
1978	288.5	285.5	66.0	26.0	0	0	0	2.0	0	11.0	6.0	77.5	762.5
1979	216.6	178.9	25.0	10.3	8.2	0	0	2.0	0	92.2	68.8	98.7	700.7
1980	23.3	165.8		38.0	0	0	0	0.0	0.1	0	36.0	55.0	
1981	108.1	119.6	38.0	3.7	0	0	0	0.5	0.0	11.5	44.0	70.5	395.9
1982	118.8	131.0	102.5	34.2	0	0	0	0.0	8.5	1.5	73.6	80.2	550.3
1983	130.0	18.5	24.0	17.5	0	25.0	0	0.0	0.0	7.0	108.5	166.5	497.0
1984	41.7	45.0	40.5	47.0	0	0	0	0.0	0.0	64.5	37.0	26.5	302.2
1985	99.0	188.5	50.5	0	0	0	0	0.0	0.0	9.5	30.2	171.0	548.7
1986		259.5											
1987	37.2	118.4	11.0	30.0	0	0	0	0	0	22.1	47.3	60.8	326.8
1988	112.0	81.0	27.0	23.0	0	0	0	0	0	7.0	21.0	68.5	339.5
1989	115.0	126.5	35.0	54.0	0	0	0	0	0	12.0	23.2	40.0	405.7
1990	115.8	48.0	233.0	89.0	0	0	0	0	0	22.0	36.5	58.1	602.4
1991	161.7	120.0	18.0	0	0	0	0	0	0	38.1	29.0	111.5	478.3
1992	34.4	49.7	41.2	0	0	0	0	0	5.0	1.5	25.3	53.7	210.8
1993	59.0	120.9	17.0	38.3	0	0	0	0	0	40.0	27.0	83.0	385.2
1994	187.0	75.0	33.5	16.5	0	0	0	0	0	0	35.5	6.0	353.5
1995	21.5	185.0	119.9	0.0	4.0	0	0	0	0	95.5	76.5	60.0	562.4
1996	112.0	33.0	18.5	22.5	0	0	0	0	0	0	27.5	116.0	329.5
1997	215.5	102.0	74.0	0.0	0	0	0	0	0	42.0	10.0	66.5	510.0
1998	123.0	28.5	35.0	0.0	0	0	0	0	0	17.5	5.0	101.0	310.0
1999	140.0	74.0	76.5	0.0	0	0	0	0	20.0	11.0	95.0	158.0	574.5
2000	102.3	108.5	55.5	20.0	29.0	0	0	0	0	5.0	15.5	21.0	356.8
2001	26.6	111.0	168.5	102.5	0	0	0	0	38.0	0	61.5	11.0	519.1
2002	30.0	24.0		12.0	0	0	0	0	0	23.0		52.5	
2003	118.7	105.5	0	12.0	0	0	0	0	0	27.1	73.4	74.0	410.7
2004	78.0	92.0	117.2	31.0	0	0	0	0	0	0			
2006	331.4	237.0	58.0	6.0	6.0	0	0	0	0	76.0	5.0	48.0	767.4
2007	96.0	58.0	56.0	37.0	0	0	0	0	0		14.0	6.0	
2008	213.0	109.0	48.3	0	1.5	0	0	0	0				
2009	193.5	265.2	5.0	0	0	0	0	0	31.5	49.7	29.1	93.4	667.4
Average	118.3	118.6	76.2	32.1	4.5	0.4	0.0	0.1	2.5	20.4	53.4	77.3	505.5
Yrs data	91	93	90	92	93	93	93	93	94	91	88	89	78
Max	335.0	370.6	254.0	185.7	59.2	25.0	2.0	5.3	38.0	95.5	184.9	206.5	936.0
Median	112.0	108.5	59.5	25.6	0.0	0.0	0.0	0.0	0.0	11.9	47.3	70.5	494.7

Grey highlight indicates no rainfall value due to Lost Record

Tsumeb (Met. Office No. 1055 3743) Seasonal Rain

Tsumeb Monthly Rainfall Information as Seasonal Totals

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
1913												6.6	
1913/14	5.6	66.0	79.5	93.0	111.8	68.3	50.5	0	0	0	0.5	0	475.2
1914/15	37.6	2.0	82.8	192.3	166.4	3.0		0.5	0	0	0.0	16.8	501.4
1915/16	0		124.2	75.4	43.9	143.3	7.1	0	0	0	0.0	0.0	393.9
1916/17	15.2	102.1	159.5	49.8	200.4	42.2	29.5	35.8	0	0	0.0	1.0	635.5
1917/18	4.8	37.3	91.4	141.0	36.3	186.2	0	0	0	0	0.0	3.8	501.1
1918/19	39.9	12.4	101.1	117.6	58.7	26.2	11.4	0	0	0	1.0	1.3	369.6
1919/20	32.3	45.2	70.4	116.8	103.6	20.1	2.8	5.8	0	0	0	0	397.0
1920/21	0	166.9	24.4	114.6	176.5	63.2	17.5	59.2	0	0	0	0	622.3
1921/22	9.7	73.7	33.5	40.1	61.2	49.0	1.0	3.0	0	0	0	0	271.2
1922/23	80.5	51.8	14.2	139.4	308.6	164.3	33.5	7.4	0	0	0	0	799.7
1923/24	12.4	24.6	45.0	52.6	92.2		0	0	0	0	0	0.5	227.3
1924/25	33.5	83.6	117.3	198.6	143.3	183.4	169.2	29.2	0	0	0	0	958.1
1925/26	0	56.6	44.7	136.7	36.1	63.5	82.6	3.6	7.1	0	0	2.5	433.4
1926/27	34.5	95.8	146.1	73.4	53.1	67.8	48.0	0	0	0	0	0	518.7
1927/28	29.2	49.5	51.1	94.2	52.6	126.7	44.2	0	0	0	0	12.7	460.2
1928/29	0.0	43.4	7.1	46.5	132.3	57.7	4.3	0	0	0	0	0	291.3
1929/30	41.7	77.0	13.0	101.1	80.8	81.8	65.8	0	0	0	0	0	461.2
1930/31	2.8	11.7	34.0	122.9	136.7	128.5	25.7	0.5	0	0	0	0	462.8
1931/32	18.8	111.8	94.2	28.4	75.7	50.5	5.1	3.6	0	0	0	0	388.1
1932/33	29.7	36.1	104.6	51.6	35.3	32.3	4.6	0	0	0	0	0	294.2
1933/34	4.1	63.0	130.3	335.0		102.4	83.3	0.3	0	0	0	0	718.4
1934/35	15.2	25.9	145.0	129.8	65.5	45.5	22.6	2.0	0	0	0	0	451.5
1935/36	8.6	56.6	98.0	81.0	71.9	151.9	14.2	15.2	0	0	0	0.5	497.9
1936/37	1.5	10.7	70.6	54.4	157.0	38.1	91.9	2.8	0	0	0	0	427.0
1937/38	29.5	73.9	133.9	204.0	198.6	17.3	48.8	11.7	0	0	0	0	717.7
1938/39	10.4	131.8	64.8	37.3	9.1	126.5	25.9	3.6	0	2.0	0	0	411.4
1939/40	31.0	47.2	168.1	193.8	48.0	96.3	35.8	0	0	0	0	0	620.2
1940/41	6.9	15.2	133.9	80.3	65.5	15.5	41.4	0	0	0	0	0.3	359.0
1941/42	33.8	7.1	29.0	103.9	141.5	213.4	25.4	0	0	0	0	0	554.1
1942/43	58.4	11.9	119.6	30.7	24.1	84.1	56.4	0	0	0	0	0	385.2
1943/44	0	68.8	206.5	300.7	370.6	54.1	5.1	0	0	0	0	0	1 005.8
1944/45	25.4	30.2	63.8	45.5	44.7	61.0	18.8	0	0	0	0	0	289.4
1945/46	11.9	130.6		61.5	44.7	26.2	6.6	0	0	0	0	4.1	285.6
1946/47	4.8	55.6	31.0	204.7	213.1	68.3	29.5	0	3.3	0	0	0.5	610.8
1947/48	2.8	87.1	116.1	67.3	212.1	42.7	29.7	4.8	0	0	0	0	562.6
1948/49	20.1	74.2	1.8	54.6	53.1	124.2	5.1	0	0	0	0	0	333.1
1949/50	1.0	79.2	48.3	171.2	223.0	127.3	185.7	34.0	0	0	0	0	869.7
1950/51	0.0	77.2	117.6	24.3	107.8	81.0	63.3	44.5	0	0	0	0	515.7
1951/52	52.2	25.9	131.9	0.0	145.0	1.8	3.6	0	0	0	0	0	360.4
1952/53	25.0	46.8	61.2	134.7	181.6	56.8	29.4	18.9	0	0	0	0.6	555.0
1953/54	20.8	71.4	121.2	183.4	220.2	254.0	58.3	0	0	0	0	4.8	934.1
1954/55	7.9	32.3	98.9	149.9	98.7	45.4	56.6	0	0	0	0	0	489.7
1955/56	34.5	38.9	130.9	174.8	262.1	136.6	37.9	23.3	0	0	0	20.3	859.3
1956/57	10.0	13.0	73.0	158.4	141.0	74.8	14.9	3.1	0	0	0	0.3	488.5
1957/58	40.0	47.8	96.3	147.1	121.5	40.6	12.1	0	0	0	0	10.6	516.0
1958/59	6.1	76.9	86.7	52.8	139.2	63.4	102.3	3.3	0	0	0	0	530.7
1959/60	6.6	15.5	102.3	108.1	302.5	16.9	56.9	2.4	0	0	0	0	611.2
1960/61	47.1	65.9	67.2	74.3	134.7	133.8	31.6	20.2	5.3	0	0	0	580.1
1961/62	0.5	118.7	65.9	61.8	180.8	29.1	17.5	0	0	0	5.3	0	479.6
1962/63	36.2	57.2	49.1	140.5	47.8	124.7	48.3	0	0	0	0	0	503.8
1963/64	6.1	152.6	44.0	39.2	31.8	30.5	20.7	0	0	0	0.3	0	325.2
1964/65	5.6	8.9	52.2	80.6	87.1	97.3	54.4	0	0.5	0	0	12.7	399.3
1965/66	3.5	74.4	62.2	241.0	65.7	78.6	37.3	0	0	0	0	24.5	587.2
1966/67	0.9	9.0	62.4	207.7	124.6	128.6	32.2	0	0	0	0	2.7	568.1
1967/68	14.9	184.9	122.0	202.0	46.0	151.0	18.4	31.3	0	0	0	0	770.5
1968/69	2.5	96.2	56.8		157.2	134.0	30.8	0	0	0	0	0	477.5
1969/70	20.1	88.3	9.4	129.3	74.2	19.5	23.8	0	0	0	0	0	364.6
1970/71	8.8	16.1	117.5	220.1	198.1	19.1	12.1	0	0	0	0	0	591.8
1971/72	30.0		9.6	125.6	38.2	179.0	10.5	0	0	0	0	0	392.9
1972/73	67.9	0	9.7	75.8	22.6	160.1	16.9	0	0	0	0	0	353.0
1973/74					167.6	73.0	61.6	0	0	0	0	0	302.2
1974/75	29.4	55.5	28.0	158.0	62.3	160.5	50.5	0	0	0	0	0	544.2
1975/76	0	68.2											68.2
1976/77						21.5	53.6	0	0	0	0	6.0	81.1
1977/78	0	83.0	73.2	288.5	285.5	66.0	26.0	0	0	0	2.0	0	824.2
1978/79	11.0	6.0	77.5	216.6	178.9	25.0	10.3	8.2	0	0	2.0	0	535.5
1979/80	92.2	68.8	98.7	23.3	165.8		38.0	0	0	0	0.0	0.1	486.9
1980/81	0	36.0	55.0	108.1	119.6	38.0	3.7	0	0	0	0.5	0.0	360.9
1981/82	11.5	44.0	70.5	118.8	131.0	102.5	34.2	0	0	0	0.0	8.5	521.0
1982/83	1.5	73.6	80.2	130.0	18.5	24.0	17.5	0	25.0	0	0.0	0.0	370.3
1983/84	7.0	108.5	166.5	41.7	45.0	40.5	47.0	0	0	0	0.0	0.0	456.2
1984/85	64.5	37.0	26.5	99.0	188.5	50.5	0	0	0	0	0.0	0.0	466.0
1985/86	9.5	30.2	171.0		259.5								470.2
1986/87				37.2	118.4	11.0	30.0	0	0	0	0	0	196.6
1987/88	22.1	47.3	60.8	112.0	81.0	27.0	23.0	0	0	0	0	0	373.2
1988/89	7.0	21.0	68.5	115.0	126.5	35.0	54.0	0	0	0	0	0	427.0
1989/90	12.0	23.2	40.0	115.8	48.0	233.0	89.0	0	0	0	0	0	561.0
1990/91	22.0	36.5	58.1	161.7	120.0	18.0	0	0	0	0	0	0	416.3
1991/92	38.1	29.0	111.5	34.4	49.7	41.2	0	0	0	0	0	5.0	308.9
1992/93	1.5	25.3	53.7	59.0	120.9	17.0	38.3	0	0	0	0	0	315.7
1993/94	40.0	27.0	83.0	187.0	75.0	33.5	16.5	0	0	0	0	0	462.0
1994/95	0	35.5	6.0	21.5	185.0	119.9	0.0	4.0	0	0	0	0	371.9
1995/96	95.5	76.5	60.0	112.0	33.0	18.5	22.5	0	0	0	0	0	418.0
1996/97	0	27.5	116.0	215.5	102.0	74.0	0.0	0	0	0	0	0	535.0
1997/98	42.0	10.0	66.5	123.0	28.5	35.0	0.0	0	0	0	0	0	305.0
1998/99	17.5	5.0	101.0	140.0	74.0	76.5	0.0	0	0	0	0	20.0	434.0
1999/2000	11.0	95.0	158.0	102.3	108.5	55.5	20.0	29.0	0	0	0	0	579.3
2000/01	5.0	15.5	21.0	26.6	111.0	168.5	102.5	0	0	0	0	38.0	488.1
2001/02	0	61.5	11.0	30.0	24.0		12.0	0	0	0	0	0	138.5
2002/03	23.0		52.5	118.7	105.5	0	12.0	0	0	0	0	0	311.7
2003/04	27.1	73.4	74.0	78.0	92.0	117.2	31.0	0	0	0	0	0	492.7
2004/05	0												
2005/06				331.4	237.0	58.0	6.0	6.0	0	0	0	0	638.4
2006/07	76.0	5.0	48.0	96.0	58.0	56.0	37.0	0	0	0	0	0	376.0
2007/08		14.0	6.0	213.0	109.0	48.3	0	1.5	0	0	0	0	391.8
2008/09				193.5	265.2	5.0	0	0	0	0	0	31.5	495.2

Grey highlight indicates no rainfall value due to Lost Record

Otjirukaku (Met. Office No. 1009 8526)

Otjirukaku 10098526	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Otjirukaku Annual Rainfall (mm)
1986	55.5	115.0	121.5	85.0	0.0	0.0	0.0	0.0	25.0	49.5	33.0	18.5	503.0
1987	36.0	147.5	91.0	69.0	0.0	0.0	0.0	0.0	0.0	55.0	41.0	87.5	527.0
1988	76.0	86.5	95.0	57.0	0.0	0.0	0.0	0.0	0.0	8.5	42.0	65.0	430.0
1989	226.0	252.0	26.5	105.5	1.5	0.0	0.0	0.0	0.0	4.5	10.0	10.0	636.0
1990	100.0	74.0	130.5	53.5	0.0	0.0	0.0	0.0	0.0	22.5	22.5	111.0	514.0
1991	95.0	169.0	105.5	0.0	0.0	0.0	0.0	0.0	0.6	35.5	40.0	101.5	547.1
1992	63.5	18.5	63.0	0.0	0.0	0.0	0.0	0.0	10.0	19.5	37.0	37.0	248.5
1993	97.0	186.0	45.0	24.0	0.0	0.0	0.0	5.0	0.0	34.0	136.5	50.0	577.5
1994	341.8	91.0	25.5	3.0	0.0	0.0	0.0	0.0	0.0	0.0	38.5	30.0	529.8
1995	12.3	101.0	41.0	0.0	8.0	0.0	0.0	0.0	9.0	7.0	46.0	68.5	292.8
1996	187.0	38.6	21.5	15.0	0.0	0.0	0.0	0.0	0.0	0.0	47.5	106.3	415.9
1997	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	-
1998	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	LR	-
1999	LR	LR	LR	LR	LR	LR	LR	LR	0.0	15.0	17.5	121.5	-
2000	169.0	216.0	99.0	36.0	10.0	0.0	0.0	0.0	0.0	52.0	3.0	27.0	612.0
2001	35.0	135.0	124.0	103.5	10.0	0.0	0.0	0.0	17.0	0.0	131.0	33.5	589.0
2002	88.0	119.5	81.0	28.0	0.0	0.0	0.0	0.0	0.0	20.0	28.0	61.0	425.5
2003	71.0	65.1	9.0	8.0	0.0	0.0	0.0	0.0	3.0	27.0	113.0	71.0	367.1
2004	90.0	52.0	87.0	76.0	0.0	0.0	0.0	0.0	0.0	81.5	44.0	83.0	513.5
2005	178.0	116.0	125.0	35.0	1.0	0.0	0.0	0.0	0.0	6.0	65.5	44.0	570.5
2006	382.0	307.0	154.0	19.0	25.0	0.0	0.0	0.0	5.0	69.0	35.0	152.0	1 148.0
2007	70.0	43.0	60.0	24.0	0.0	0.0	0.0	0.0	0.0	39.0	30.0	11.0	277.0
2008	181.0	167.0	141.1	5.0	0.0	0.0	0.0	0.0	0.0	2.2	110.0	138.0	744.3
2009	111.0	192.0	72.0	6.0	31.0	0.0	0.0	0.0	9.6	22.0	60.0	99.0	602.6
2010	38.1	61.0	99.0	38.0	9.0	LR	LR	LR	LR	LR	LR	81.0	-
2011	LR	LR	LR	LR	6.0	0.0	0.0	0.0	0.0	0.0	72.0	92.0	-
2012	234.0	154.0	74.0	23.0	0.0	0.0	0.0	0.0	0.0	19.0	52.0	85.0	641.0
2013	100.0	LR	LR	0.0	0.0	0.0	0.0	0.0	0.0	1.4	22.0	LR	-
2014	36.0	274.0	187.9	43.0	LR	LR	LR	0.0	0.0	28.0	54.0	57.0	679.9
2015	66.0	41.0	87.0	45.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	61.0	302.0
Mean	120.7	128.9	86.6	34.7	3.9	0.0	0.0	0.2	2.9	23.0	49.3	70.5	528.9
Max	382.0	307.0	187.9	105.5	31.0	0.0	0.0	5.0	25.0	81.5	136.5	152.0	1 148.0
Median	92.5	116.0	87.0	26.0	0.0	0.0	0.0	0.0	0.0	19.5	41.0	68.5	528.4

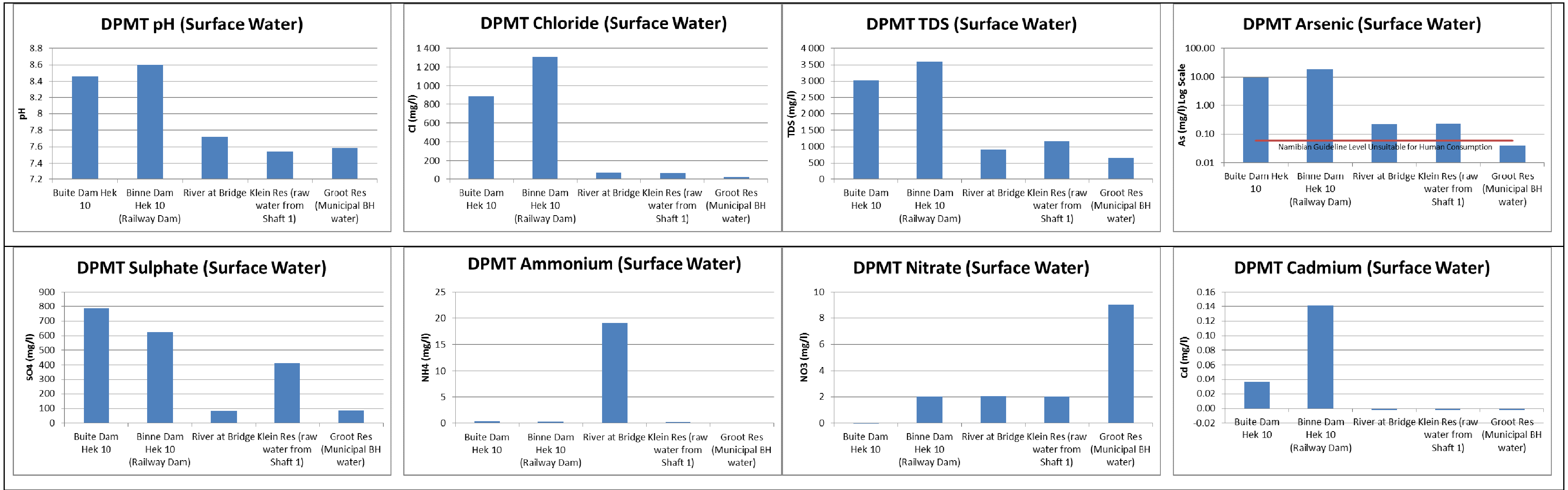
Yellow highlight in last column indicates no annual rainfall value calculated due to Lost Record

APPENDIX 3: DPMT WATER QUALITY DATA (OCTOBER 2015)

Lab no	Locality	Sampled date	20 - pH	20 - EC	26 - TDS - cal	01 - Alk	02 - Cl	03 - SO4	06 - NO3	05 - NH4	04 - PO4	08 - F	30 - Ca	30 - Mg	30 - Na	30 - K	31 - Al	31 - Fe	31 - Mn	31 - Cr	31 - Cu	31 - Ni
				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	mg/l	mg/l	mg/l	mg/l	mg/l
234545	Buite Dam Hek 10	05-Nov-2015	8.46	458	3024	523	891	787	-0.118	0.365	3.13	2.22	279	114	584	11.5	-0.002	0.042	-0.002	-0.003	0.071	-0.002
234546	Binne Dam Hek 10 (Railway Dam)	05-Nov-2015	8.6	556	3586	650	1305	624	1.99	0.308	8.08	2.57	317	109	775	8.77	-0.002	-0.004	-0.002	-0.003	0.105	-0.002
234547	River at Bridge	05-Nov-2015	7.72	139	903	646	74.4	83.8	2.04	19.1	2.05	0.419	125	72.8	76.7	10.2	-0.002	-0.004	-0.002	-0.003	-0.002	-0.002
234548	Klein Res (raw water from Shaft 1)	05-Nov-2015	7.54	152	1164	477	72	412	2.02	0.222	0.1	0.683	180	75.9	86.6	6.51	-0.002	-0.004	0.062	-0.003	-0.002	-0.002
234549	Groot Res (Municipal BH water)	05-Nov-2015	7.58	97.2	667	490	19.2	87.7	9.01	0.1	-0.002	0.241	114	60.8	21.2	2.17	-0.002	-0.004	-0.002	-0.003	-0.002	-0.002

Lab no	Locality	Sampled date	31 - Zn	31 - Co	31 - Cd	31 - Pb	26 - Thard - cal	34 - As	34 - Se	32 - Ag	32 - B	32 - Ba	32 - Be	32 - Bi	32 - Ga	32 - Li	32 - Mo	32 - Rb	32 - Sr	32 - Te	32 - Tl	32 - V
			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	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
234545	Buite Dam Hek 10	05-Nov-2015	0.512	-0.002	0.036	-0.003	1169	9.52	-0.005	-0.001	0.174	0.094	0.001	0.152	0.02	0.075	0.437	0.172	0.983	0.016	-0.037	-0.001
234546	Binne Dam Hek 10 (Railway Dam)	05-Nov-2015	0.305	-0.002	0.141	-0.003	1240	18.7	-0.005	-0.001	0.154	0.095	-0.001	0.021	0.022	0.028	0.42	0.05	1.11	0.002	-0.037	-0.001
234547	River at Bridge	05-Nov-2015	-0.002	-0.002	-0.002	-0.003	612	0.222	-0.005	-0.001	0.075	0.058	-0.001	0.048	0.008	0.014	0.027	0.043	0.37	-0.001	-0.037	-0.001
234548	Klein Res (raw water from Shaft 1)	05-Nov-2015	1.42	-0.002	-0.002	-0.003	761	0.228	-0.005	-0.001	0.062	0.051	-0.001	-0.004	0.01	0.019	0.036	0.03	0.491	-0.001	-0.037	-0.001
234549	Groot Res (Municipal BH water)	05-Nov-2015	0.185	-0.002	-0.002	-0.003	535	0.04	-0.005	-0.001	0.035	0.089	-0.001	0.02	0.01	0.007	0.018	0.025	0.367	-0.001	-0.037	-0.001

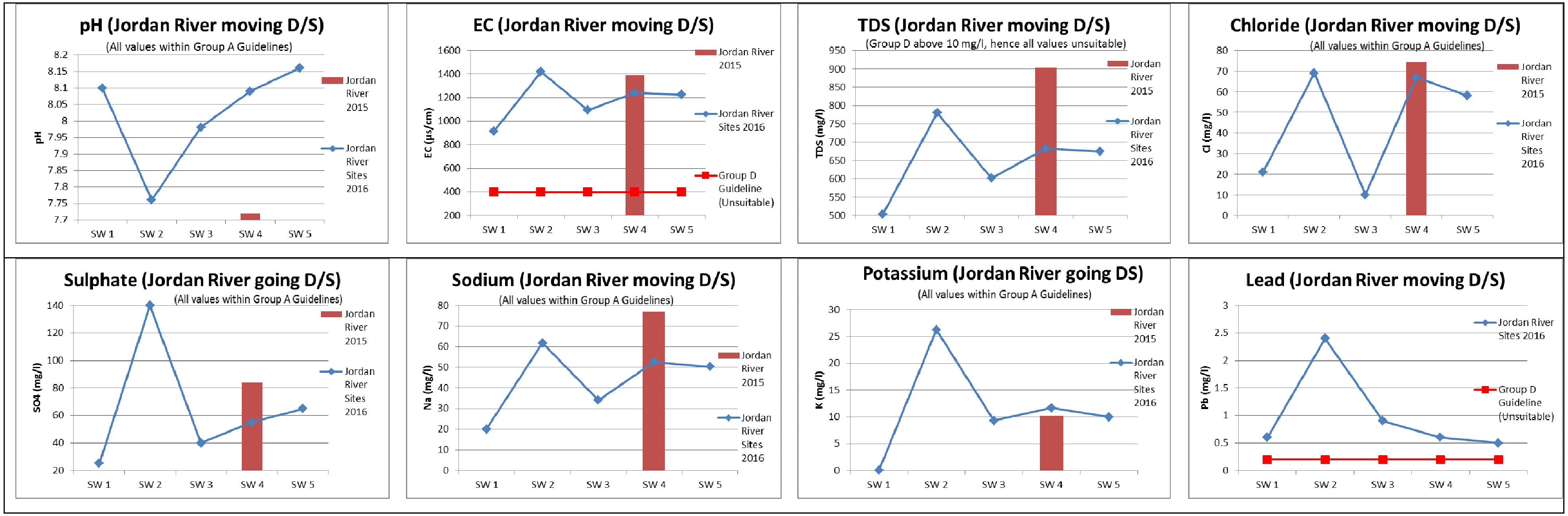
Graphs of various parameters from DPMT sampling October 2015



APPENDIX 4: JORDAN RIVER WATER QUALITY DATA (JUNE 2016)

Date	Sample Name	pH	Conductivity	TDS	Total Alkalinity	Chloride	Total Hardness	Calcium Hardness	Magnesium Hardness	Sulfates	Arsenic	Lead	Iron	Manganese	Zinc	Sodium	Potassium	Calcium	Magnesium	MoO$_4$
			µs/cm	mg/l	mg/l as $CaCO_3$	mg/l Cl-	mg/l as $CaCO_3$	mg/l as $CaCO_3$	mg/l as $CaCO_3$	mg/l as SO_4	mg/l As	mg/l Pb	mg/l Fe	mg/l Mn	mg/l Zn	mg/l Na	mg/l K	mg/l Ca	mg/l Mg	mg/l
20/06/2016	SW 1	8.1	916	504	410	21	611	353	258	25	0	0.6	0.093	0.402	0	20	<5	141	62.8	<0.01
20/06/2016	SW 2	7.76	1418	780	540	69	629	343	286	140	<0.01	2.4	0.04	0.083	0.1	61.8	26.3	137	69.8	<0.01
20/06/2016	SW 3	7.98	1095	602	450	10	621	335	286	40	<0.01	0.9	<0.01	0.104	0	34	9.3	134	69.8	<0.01
20/06/2016	SW 4	8.09	1240	682	480	67	653	355	298	55	<0.01	0.6	<0.01	0.117	0	52.6	11.7	142	72.6	<0.01
20/06/2016	SW 5	8.16	1225	674	460	58	652	356	296	65	<0.01	0.5	<0.01	0.118	0	50.3	10	142	72.3	<0.01

Graphs of various parameters from Jordan River sampling June 2016



Only 1 Jordan River site sampled in 2015

RECORD OF REPORT DISTRIBUTION

SLR Reference:	733.14028.00005
Title:	Dundee Smelter Expansion Environmental Impact Assessment, Groundwater and Surface Water Study
Report Number:	2016-WG-28
Proponent:	Dundee Precious Metals, Tsumeb

Name	Entity	Copy No.	Date issued	Issuer

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