East OFS Project Residue Disposal Plan - Groundwater Specialist Study

Report Prepared for

Tronox Mineral Sands (Pty) Ltd

Report Number 548215/GW

Report Prepared by

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East OFS Project Residue Disposal Plan - Groundwater Specialist Study

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Profile and Expertise of Specialists

SRK Consulting (South Africa) (Pty) Ltd (SRK) has been appointed by Tronox Mineral Sands (Pty) Ltd (Tronox) to undertake an Environmental Impact Assessment (EIA) process required in terms of the National Environmental Management Act 107 of 1998 (NEMA). SRK has appointed a team of professionals to conduct the Groundwater Impact Assessment as part of the EIA process. SRK Consulting comprises over 1 400 professional staff worldwide, offering expertise in a wide range of environmental and engineering disciplines. SRK's Cape Town environmental department has a distinguished track record of managing large environmental and engineering projects, extending back to 1979. SRK has rigorous quality assurance standards and is ISO 9001 accredited.

In accordance with the EIA Regulations, 2014, the qualifications and experience of the key individual specialists involved in the study are detailed below.

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Registered Environmental Assessment Practitioner (EAP) No. 2019/413
Chris Dalgliesh is a Partner and Principal Environmental Consultant with over 33 years' experience, primarily in South Africa, Southern Africa, West Africa and South America (Suriname). Chris has worked on a wide range of projects, notably in the natural resources, Oil & Gas, waste, infrastructure (including rail and ports) and industrial sectors. He has managed and regularly reviews Groundwater Impact Assessments. He has directed and managed numerous Environmental and Social Impact Assessments (ESIAs) and associated management plans, in accordance with international standards. He regularly provides high level review of ESIAs, frequently directs Environmental and Social Due Diligence studies for lenders, and also has a depth of experience in Strategic Environmental Assessment (SEA), State of Environment Reporting and Resource Economics. He holds a BBusSci (Hons) and M Phil (Env).

Specialist Consultant: Sheila Imrie, BSc (Hons); MSc (Hydrogeology)
Registered Professional Natural Scientist (Pr.Sci.Nat) (Water Science and Mathematical Science) No. 400263/09
Sheila Imrie is a Principal Hydrogeologist with over 20 years of experience in groundwater resources and IT in South Africa and the UK. She specialises in aquifer test and data analysis, tailings seepage modelling and groundwater conceptual and numerical modelling. Sheila has generated numerous high-quality groundwater flow and transport models for both industry and government and is well respected for undertaking external numerical model reviews. Sheila regularly works on both international and national projects.

Specialist Consultant: Annalisa Vicente, BSc (Hons); MSc (Environmental & Water Science)
Annalisa Vicente is a Hydrogeologist and Groundwater Modeller. She has worked on a range of groundwater projects, including groundwater contamination investigations, remediation and environmental risk assessments. She is therefore proficient in the characterisation of groundwater, its occurrence, movement and hydrochemistry, elements needed for groundwater conceptual modelling and subsequent numerical model development.

Statement of SRK Independence

Neither SRK nor any of the authors of this report have any material present or contingent interest in the outcome of this assessment, nor do they have any pecuniary or other interest that could be reasonably regarded as being capable of affecting their independence or that of SRK. SRK has no beneficial interest in the outcome of the assessment capable to affect its independence.

Disclaimer

The opinions expressed in this report have been based on the information supplied to SRK by Tronox. SRK has exercised all due care in reviewing the supplied information, but conclusions from the review are reliant on the accuracy and completeness of the supplied data. SRK does not accept responsibility for any errors or omissions in the supplied information and does not accept any consequential liability arising from commercial decisions or actions resulting from them. Opinions presented in this report apply to the site conditions and features as they existed at the time of SRK's investigations, and those reasonably foreseeable. These opinions do not necessarily apply to conditions and features that may arise after the date of this Report, about which SRK had no prior knowledge nor had the opportunity to evaluate.

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List of Acronyms and Abbreviations

amsl	Above mean sea level
c.	Circa (approximately)
CVFD	Control Volume Finite Difference
d	day
DEM	Digital Elevation Model
DMRE	Department of Mineral Resources and Energy
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
EMPr	Environmental Management Programme
EOFS	East Orange Feldspathic Sand
GRAII	Groundwater Resource Assessment Phase 2
HM	Heavy Minerals
K	Hydraulic Conductivity
KFC	Koegel Fontein Complex
LIDAR	Light Detection and Ranging
L/s	Litres per second
LoM	Life of Mine
Ltd	Limited
m	meter
MAR	Mean Annual Runoff
MLM	Matzikama Local Municipality
MRRDA	Mineral and Petroleum Resourced Development Act 28 of 2002
mm	millimetre
NEMA	National Environmental Management Act 107 of 1998
NEM: WA	National Environmental Management: Waste Act 59 of 2008
NMC	Namaqualand Metamorphic Complex
OFS	Orange Feldspathic Sand
PCP	Primary Concentration Plant
Pty	Proprietary
RAS	Red Aeolian Sand
RSF	Residue Storage Facilities
S	Storativity
SANS	South African National Standard
SCP	Secondary Concentrator Plant
STF	Sand Tailings Facility
SRK	SRK Consulting (South Africa) (Pty) Ltd
subWMA	Sub-Water Management Area

S&EIR	Scoping and Environmental Impact Reporting
T	Transmissivity
Tronox	Tronox Mineral Sands (Pty) Ltd
ToR	Terms of Reference
WCDM	West Coast District Municipality
WMA	Water Management Area

Glossary

Aquifer	Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.
Baseflow	The flow of water in a stream or river that is derived from the seepage of groundwater and/or through flow into the surface watercourse. At times of peak river flow, baseflow forms only a small proportion of the total flow, but in periods of drought it may represent nearly the total flow, often allowing a stream or river to flow even when no rain has fallen for some time.
Baseline	Information gathered at the beginning of a study which describes the environment prior to development of a project, and against which predicted changes (impacts) are measured.
Environmental Impact Assessment	A process of evaluating the environmental and socio-economic consequences of a proposed course of action or project.
Environmental Management Plan	A description (in an ESIA Report or separate document) of the means (or the environmental specification) for achieving environmental objectives and targets during all stages of a specific proposed activity.
Geohydrology	(The study of) groundwater flow.
Groundwater Discharge	The removal/loss of water from the saturated zone of an aquifer.
Groundwater Flow Model	The application of a mathematical model to represent a regional or site-specific groundwater flow system
Groundwater Mounding	A localised rise in the water table due to infiltration.
Hydraulics	(The study of) water flow.
Hydrology	(The study of) surface water flow.
Leachate	Liquid that drains from a material and contains significantly elevated concentrations of undesirable material derived from the material that it has passed through.
Mitigation Measures	Design or management measures that are intended to avoid and / or minimise or enhance an impact, depending on the desired effect. These measures are ideally incorporated into a design at an early stage.
Model Calibration	The adjustment of model parameters in order to achieve or predict real life environmental conditions.
Monitored Natural Attenuation	The monitoring of groundwater to confirm whether natural attenuation processes (such as dilution and biodegradation) are acting at a sufficient rate to ensure that the wider environment is unaffected and that remedial objectives will be achieved within a reasonable timescale.
Natural Attenuation	A variety of physical, chemical and biological processes that, under favourable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume and concentration of contaminants in soil and water. These in situ processes include biodegradation, dispersion, dilution, sorption, volatilisation, stabilisation, transformation and destruction of contaminants.
Palaeochannels	An inactive river or stream channel that has been either filled or buried by younger sediment.

1 Introduction

1.1 Project Description

Tronox Mineral Sands (Pty) (Ltd) (Tronox) mines heavy mineral sands at the existing Namakwa Sands Mine at Brand se Baai. Tronox use open-cast strip-mining methods at the East Mine and West Mine, in accordance with approved Environmental Management Programmes (EMPrs) and within an authorised mining area.

The East Mine is currently a shallow mine, where mining of only the top Red Aeolian Sand (RAS) layer occurs. Mined material (sand ore) is processed at the Primary Concentration Plant at the East Mine (PCP East) to produce a heavy mineral concentrate. Waste products from the PCP East include sand tailings (coarser material) and (finer) residue called fines. Sand tailings are backfilled into the mining void(s), and slurried residue is disposed of in Residue Storage Facilities (RSFs).

Tronox is authorised to also mine and process the deeper Orange Feldspathic Sand (OFS) resource underlying the RAS material at the East Mine (known as the EOFS Project). For the EOFS Project to proceed, Tronox must modify the approved residue disposal plan (this project): this entails a single RSF to accommodate all fine residue from the project (as opposed to three smaller RSFs as per the current EOFS Project authorisation), changes to the backfill operation into shallow deposition areas and deeper deposition and “building” of sand tailings (also referred to as Sand Tailings Facilities - STFs) an Overburden Stockpile and the upgrade of infrastructure.

SRK Consulting (South Africa) Pty Ltd (SRK) has been appointed by Tronox to undertake the Scoping and Environmental Impact Reporting (S&EIR, also referred to as EIA) process required in terms of the National Environmental Management Act 107 of 1998 (NEMA) and the NEM: Waste Act 59 of 2008 (NEM: WA). The EIA process is being undertaken in accordance with the EIA Regulations, 2014. A Groundwater Impact Assessment is one of the specialist studies commissioned for the EIA.

1.2 Groundwater Study Objectives

The primary aims of this study are to describe the hydrogeological baseline environment, assess the groundwater impacts and provide recommendations for the mine rehabilitation and closure. More specifically, the objectives for the study are as follows:

- Describe the baseline hydrogeological characteristics of the study area, including the climate, topography, hydrology, geology, hydrogeology and prevailing groundwater conditions (groundwater levels and contaminants);
- Review screening work undertaken and update background information on, *inter alia*, latest monitoring data (groundwater levels and water quality) and mine plan;
- Update the existing numerical groundwater model of the site with the new baseline information as well as the proposed EOFS Project design;
- Simulate and run numerous predictive scenarios based on project design alternatives (liner vs. no liner);
- Identify and assess the potential impacts on groundwater resources per scenario, which include:
    - Quantifying groundwater seepage;
    - Quantifying groundwater inflows and outflows from various sources and sinks (water balance);
    - Quantifying mine water returns from the RSF, Tailings (shallow area and STFs) and Overburden Stockpile; and
    - Evaluating the contaminant plume footprint and concentration.

- Conduct an impact assessment which includes:
  - Assessing the direct, cumulative and indirect impacts resulting from the proposed development in relation to proposed and existing developments in the surrounding area (most importantly, planned mining operations at Namakwa Sands); and
  - A waste classification.
- Meet with Tronox to discuss the groundwater impact assessment results;
- Recommend measures to reduce hydrogeological impacts to a tolerable level;
- Recommend updates to Tronox's groundwater monitoring programme if necessary; and
- Make recommendations for rehabilitation and closure planning.

1.3 Content of the Report

The EIA Regulations, 2014 (R982 of 2014, as amended by R326 of 2017), prescribe the required content of a specialist report prepared in terms of the EIA Regulations, 2014. These requirements, and the sections of this Groundwater Impact Assessment in which they are addressed, are summarised in Table 1-1.

Table 1-1: Required Content of a Specialist Report

App 6	Item	Section
(a) (i)	Details of the specialist who prepared the report;	Page ii
(a) (ii)	Expertise of that specialist to compile a specialist report, including a curriculum vitae,	Page ii, App A
(b)	A declaration that the specialist is independent in a form as may be specified by the competent authority;	App B
(c)	An indication of the scope of, and the purpose for which, the report was prepared;	1.2
(cA)	An indication of the quality and age of base data used for the specialist report;	2 and 3
(cB)	A description of existing impacts on the site, cumulative impacts of the proposed development and levels of acceptable change;	6
(d)	The duration, date and season of the site investigation and the relevance of the season to the outcome of the assessment;	4
(e)	A description of the methodology adopted in preparing the report or carrying out the specialised process inclusive of equipment and modelling used;	5.2
(f)	Details of an assessment of the specific identified sensitivity of the site related to the proposed activity or activities and its associated structures and infrastructure, inclusive of a site plan identifying site alternatives;	5.8
(g)	An identification of any areas to be avoided, including buffers;	6
(h)	A map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers;	6
(i)	A description of any assumptions made and any uncertainties or gaps in knowledge;	5.7.2
(j)	A description of the findings and potential implications of such findings on the impact of the proposed activity or activities;	5
(k)	Any mitigation measures for inclusion in the EMPr;	6
(l)	Any conditions for inclusion in the environmental authorisation;	6
(m)	Any monitoring requirements for inclusion in the EMPr or environmental authorisation;	6
(n) (i)	A reasoned opinion whether the proposed activity or portions thereof should be authorised;	6

App 6	Item	Section
(n) (iA)	A reasoned opinion regarding the acceptability of the proposed activity or activities;	6
(n) (ii)	If the opinion is that the proposed activity, activities or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan;	6
(o)	A description of any consultation process that was undertaken during the course of preparing the specialist report;	n/a
(p)	A summary and copies of any comments received during any consultation process and where applicable all responses thereto; and	n/a
(q)	Any other information requested by the competent authority.	n/a

2 Site Description

2.1 Site Locality

The Mine is located at Brand se Baai which lies in the magisterial district of Vanrhynsdorp, in the Matzikama Local and West Coast District Municipalities of South Africa (MLM and WCDM respectively). The Mine area is remote, with the nearest formal community of Koekenaap located more than 50 km to the south-east of the Mine site. The nearest town to the Mine (Lutzville) lies c.63 km to the south-east along the R363 (see Figure 2-1).

Tronox existing mining operations are covered by two converted Mining Rights, namely WC30/5/1/2/2/113 and WC30/5/1/2/2/114, and a third new Mining Right, namely WC30/5/1/2/2/100400MR issued by the Department of Mineral Resources and Energy (DMRE) in terms of the Mineral and Petroleum Resourced Development Act 28 of 2002 (MPRDA) on 18 August 2008 and 22 February 2016 respectively. Tronox is authorised in terms of the MPRDA to operate (prospect and mine) within this Mining Right Area in terms of a number of existing approved EMPrs.

Tronox extracts heavy minerals (HM) using opencast strip-mining methods from the East Mine and the West Mine, and the Mine precinct comprises long-term surface infrastructure to support mining, including administration and workshop buildings, two large Primary Concentrator Plants (PCPs) and a Secondary Concentrator plant (SCP), a seawater pump station (intake) near Brand se Baai, fresh water and seawater storage dams and eleven RSFs (fines dams) with a total surface area of *c.*600 ha, tailings and rejects stockpiles, a wide network of haul roads and conveyors and earthmoving machinery and equipment.

The delineation of the regional study area is based on assumed groundwater divides, such that the conceptual water balance for the area does not include significant lateral inflows from inland aquifers outside the study area. The study area includes the portions of quaternary catchments F60B, F60C, F60D and F60E. The study area is defined by the quaternary catchments in the east and the coastline in the west. In the north and south the study area boundary runs parallel to the assumed groundwater flow direction. Details of the quaternary catchments within the study area are shown in Table 2-1 and the location of the study area and the mine are depicted in Figure 2-1.

Table 2-1: Quaternary Catchments Within the Study Area

Quaternary Catchment	Quaternary Catchment Area	Quaternary Catchment	Quaternary Catchment Area
F60B	320 (*c.*32 Ha)	320 (*c.*32 Ha)	100
F60C	621 (*c.*62 Ha)	471 (*c.*47 Ha)	75
F60D	480 (*c.*48 Ha)	480 (*c.*48 Ha)	100
F60E	797 (*c.*80 Ha)	484 (*c.*48 Ha)	60

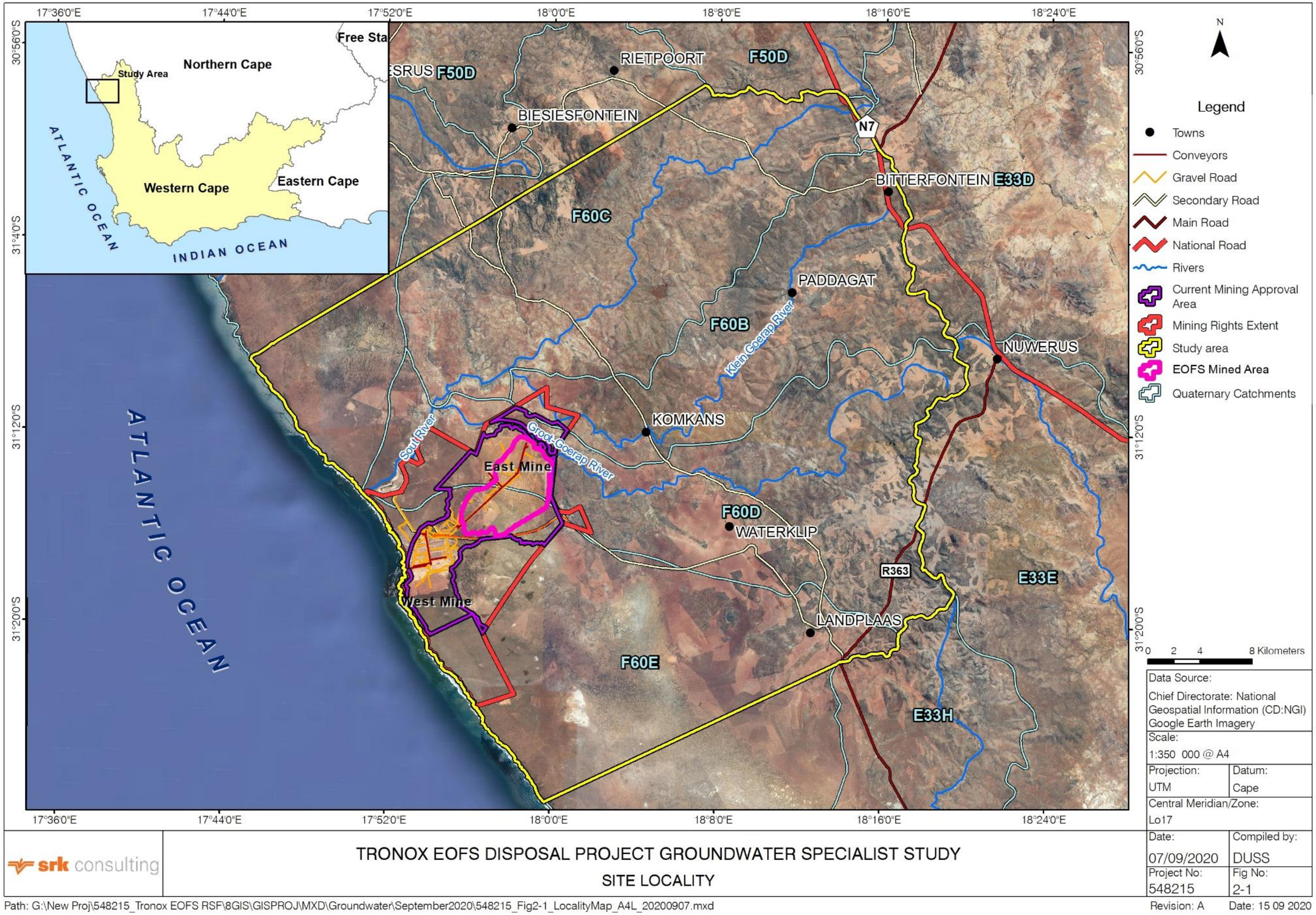


Figure 2-1: Site Locality

2.2 Climate

Namakwa Sands is located in an arid environment with average temperatures of *c.*16 °*C.* The maximum recorded temperature was 42.5°C in March 2017 and the minimum temperature was 4.6°C recorded in July 2016 (Council for Scientific and Industrial Research meteorological station at Brand se Baai, 2011 – 2018 data).The Symons Pan (S-Pan) evaporation method was used (developed by the Water Resources of South Africa, 2005), which assumed a co-efficient of 0.75 of the stated average (*c.*1 587 mm per annum), equating to *c.*1 190 mm per annum.

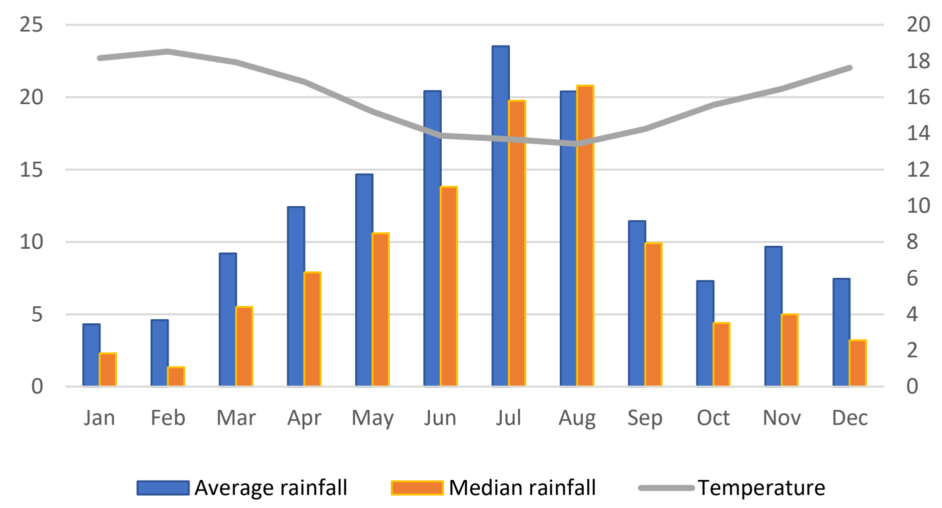
The site and its surrounds experience hot dry summers and very low rainfall winters. The area receives rain throughout the year, with most of it occurring between the months of May and August (Table 2-3). The mean annual rainfall from 1993 to 2018 was *c.*140 mm/a, although it is evident that the years since 2013 have been dominated by dry weather patterns which caused the drought experienced in the region.

Long-term monthly rainfall is presented in Table 2-2 and the total annual rainfall is presented in Figure 2-2. The total rainfall over the years vary between *c.*60 mm/a and *c.*550 mm/a. One of the major contributors to precipitation in the area is fog, which contributes up to 252.9 mm/a over 100 days of the year (Anglo American Corporation, 1990).

Table 2-2: Monthly Rainfall Data (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	4.3	4.6	9.2	12.4	14.7	20.4	23.5	20.4	11.4	7.3	9.7	7.5
Median	2.3	1.4	5.5	7.9	10.6	13.8	19.8	20.8	9.9	4.4	5.0	3.2
Min	0.0	0.0	0.2	1.5	1.0	0.8	0.0	1.0	0.0	0.2	0.0	0.0
Max	26.8	65.4	30.2	48.2	66.4	71.5	67.8	49.0	43.6	40.9	42.4	41.4

Note: Source – Council for Scientific and Industrial Research meteorological station at Brand se Baai data (2011 – 2018).



East OFS Project Residue Disposal Plan - Groundwater Specialist Study
Long-term Monthly Average Temperature and Rainfall Data

Project No. 548215

Figure 2-2: Long-term Monthly Average Temperature and Rainfall Data

Note: Source – Council for Scientific and Industrial Research meteorological station at Brand se Baai data (1992 – 2018).

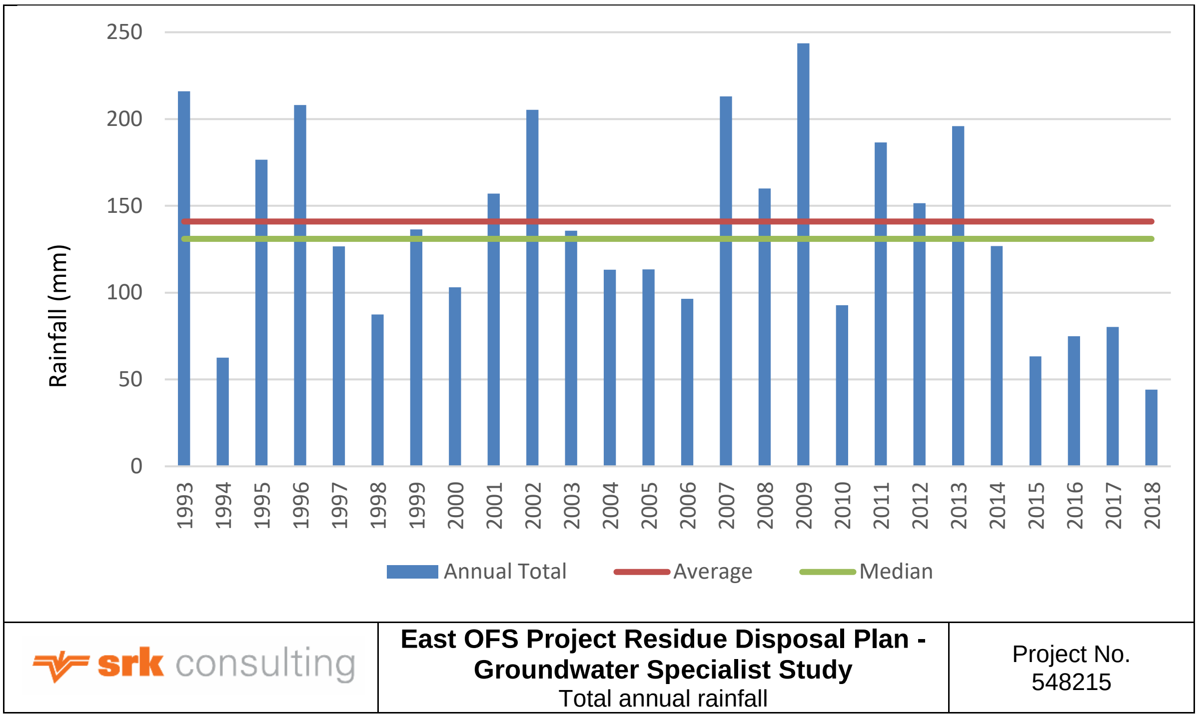


Figure 2-3: Total Annual Rainfall

Note: Source – Council for Scientific and Industrial Research meteorological station at Brand se Baai data (1993 – 2018).

2.3 Topography

The study area is characterised by undulating topography sloping gently to the west (Figure 2-4). The inland area is covered with vegetated sand dunes aligned north to south. The highest elevation is in the east of the study area gradually decreasing towards the coast in the west. Elevations range from >300 m above mean sea level (mamsl) along the eastern boundary down to 0 mamsl along the western coastal boundary of the study area.

There are various geographical areas of interests. These include the local rounded hills (koppies) known as Grouwduin se Kop, Kalkbaken se Kop and Blouklippies se Kop. A dominant ridgeline also exists between the Groot and Klein Goeraap river systems.

A steep-sided valley system, *c.*30 km long and *c.*100 m deep, follows the course of the Sout River estuary on the northern boundary of the mining area. The estuary is a severely degraded system and is currently worked as a saltpan (Golder Associates, 2011).

Elevations at the mine range from *c.*150 mamsl in the east to 0 mamsl in the west. The highest elevation occurs along a ridge in the southeast of the mine site. This ridge borders the geographical depression (calcrete pan) known as Hartebeestekom. The depression is 5 to 6 km in diameter (Golder Associates, 2011) and is noted for its geographical interest and biodiversity.

The southern and eastern portions of the mining site include rocky areas characterised by surface concentrations of quartz pebbles. These areas are geographically and biologically distinct from the surrounding dune sands.

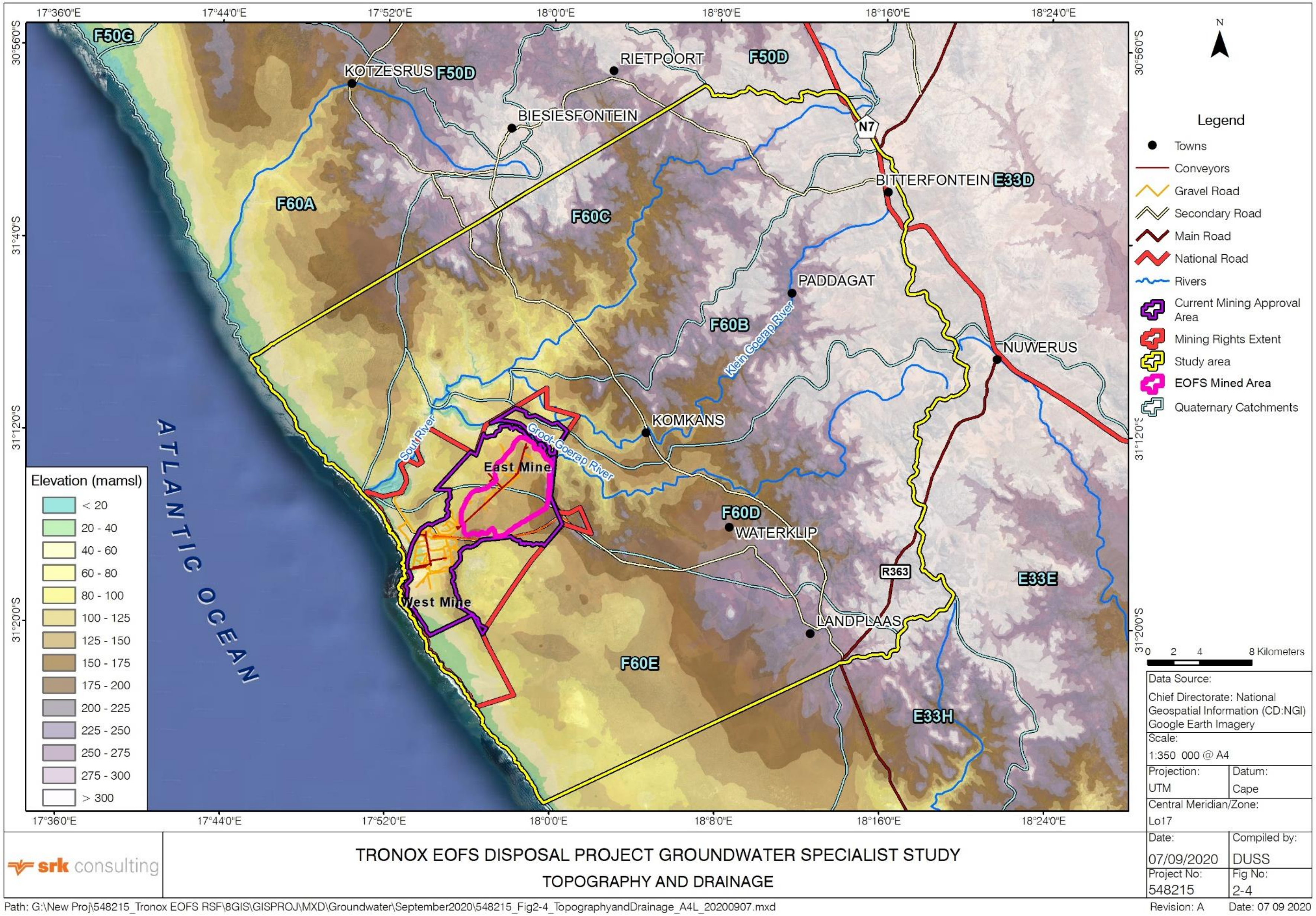


Figure 2-4: Topography and Drainage

2.4 Geology

The study area is underlain by unconsolidated and semi-consolidated sediments of Quaternary age. These sediments overlie meta-sediments of the Vanrhynsdorp Group, the metamorphic rocks of the Namaqualand Metamorphic Complex (NMC), as well as granites and dykes of the Koegel Fontein Complex (KFC).

Unconsolidated and/or semi-consolidated sediments overlying the basement rock formations at the EOFS Mine comprise:

- Dune deposits;
- Littoral (shoreline) deposits;
- Alluvial deposits (associated with the presence of preferential flow paths in the basement); and
- Wind transported deposits.

The sands decrease in age in a westward direction towards the coast.

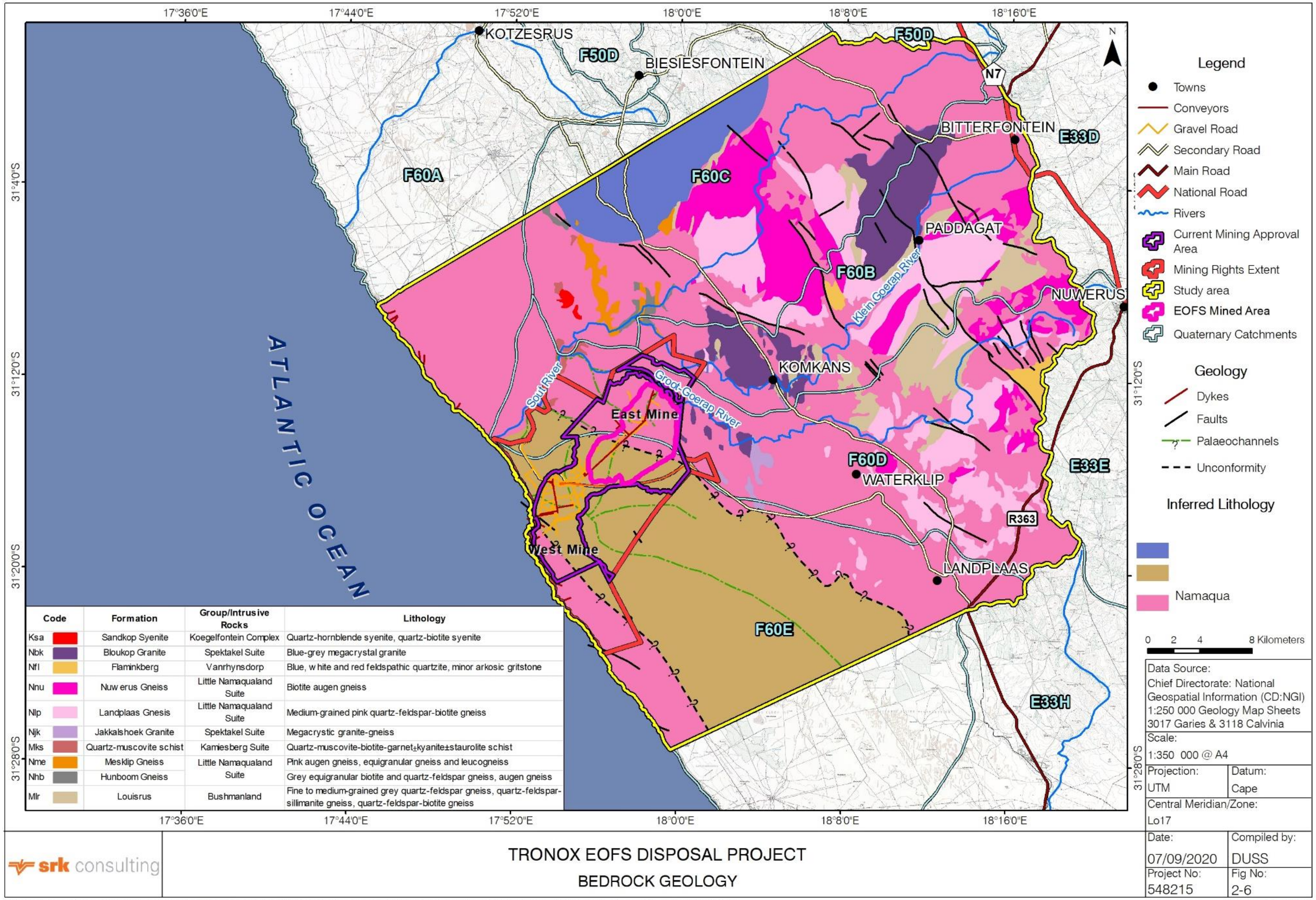
In the East Mine, surface RAS has a pre-mining thickness of between 1 and 3 m. This material is a dark reddish-brown, medium-grained sand that blankets the whole of the area inland of the rocky shore and younger dune fields being both a dune and littoral deposit.

The OFS unit underlies the RAS. This unit is a fine to medium-grained, somewhat clayey unit that comprises quartz sand with a significant proportion of feldspar and other silicates. It is generally a dark yellowish-brown to greenish colour with very little sorting, classified as a dune and littoral deposit (Figure 2-5). Pedocrete lenses (known locally as dorbank) are present in the upper OFS and were formed by upward migrating meteoric waters depositing silica and carbonate cementing agents during near-surface evaporation.

srk consulting	**East OFS Project Residue Disposal Plan - Groundwater Specialist Study** EOFS trial pit in the East Mine	Project No. 548215

Figure 2-5: EOFS Trial Pit in the East Mine

Source: S Reuther, 5 November 2019



Code	Formation	Group/Intrusive Rocks	Lithology
Ksa	Sandkop Syenite	Koegelfontein Complex	Quartz-hornblende syenite, quartz-biotite syenite
Nbk	Bloukop Granite	Spektakel Suite	Blue-grey megacrystal granite
Nfl	Flaminkberg	Vanrhynsdorp	Blue, white and red feldspathic quartzite, minor arkosic gritstone
Nnu	Nuwerus Gneiss	Little Namaqualand Suite	Biotite augen gneiss
Nlp	Landplaas Gnesis	Little Namaqualand Suite	Medium-grained pink quartz-feldspar-biotite gneiss
Njk	Jakkalshoek Granite	Spektakel Suite	Megacrystic granite-gneiss
Mks	Quartz-muscovite schist	Kamiesberg Suite	Quartz-muscovite-biotite-garnet±kyanite±staurolite schist
Nme	Meskip Gneiss	Little Namaqualand Suite	Pink augen gneiss, equigranular gneiss and leucogneiss
Nhb	Hunboom Gneiss		Grey equigranular biotite and quartz-feldspar gneiss, augen gneiss
Mlr	Louisrus	Bushmanland	Fine to medium-grained grey quartz-feldspar gneiss, quartz-feldspar-sillimanite gneiss, quartz-feldspar-biotite gneiss

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Figure 2-6: Bedrock Geology

2.5 Hydrology

The study area falls within the Olifants/Doorn Water Management Area (WMA) and the Knersvlakte Sub-Water Management Area (subWMA).

The ephemeral Groot Goeraap and Sout Rivers are the main surface drainage features in the area (Figure 2-4). The Sout River flows north-west of the Mine and drains in a south-westerly direction. These rivers have gentle gradients, are sandy, and are characterised by having broad channels *(c.*20 m at their narrowest, and frequently wider than 150 m).

The mean annual runoff (MAR) of the catchment is 0.7 mm. In South Africa, a MAR of 0.7 mm is considered to be very low and explains the limited number of well-defined drainage lines in the area.

Surface flow is extremely rare due to the low MAR, and sandy unconsolidated, flat and sparsely vegetated nature of the receiving environment.

srk consulting	**East OFS Project Residue Disposal Plan - Groundwater Specialist Study** Groot Goeraap River with mining area	Project No. 548215

Figure 2-7: Groot Goeraap River Course with Mining Area in the Background (to the South)

Source: Nick Helme Botanical Surveys (2014)

3 Prevailing Groundwater Conditions

3.1 Aquifers

Primary Aquifer

Quaternary sediments form the Primary Aquifer at the East Mine. This aquifer has relatively medium to high hydraulic conductivity (K), except at pedocrete (dorbank) lenses. In terms of hydraulic conductivity in the Primary Aquifer, the following observations are noted:

- Vertical recharge to groundwater is relatively rapid (usually <1 month);
- Local horizontal flows and temporary perched water tables are evident above the dorbank;
- Water levels are raised/mounded, based on decant observations in the Groot Goeraap River, when RAS tailings backfill took place in close proximity (c.1 km). Greater dissipation of potential groundwater mounding is anticipated below leachate sources, e.g. the RSF, Tailings (shallow areas and STFs) and Overburden Stockpile; and
- Relatively rapid contaminant transport is anticipated via advection.

The Primary Aquifer has relatively low yields for potential groundwater users in the area, with private borehole yields of <0.5 L/s, noted during a previous hydrocensus. Groundwater levels are deep (> 40 mbgl over most of the East Mine - SRK, 2019) with a poor natural background water quality (mean EC *c.*1000 mS/m) which significantly exceeds potable water standards (150 mS/m). The poor water quality, low yields and deeper water levels result in limited saturation thickness as well as non-potable water in the Primary Aquifer; consequently, private groundwater users are less reliant on the Primary Aquifer as a source of water.

Previous desktop studies have inferred that preferential groundwater flow pathways exist, possibly comprising two northern pathways which direct groundwater towards the Groot Goeraap River and Sout River and a southern pathway directing groundwater towards the coastline. The location of these preferential pathways is the subject of continued studies.

Secondary Aquifer

The Vanrhynsdorp Group and NMC bedrock form the secondary fractured aquifer at the East Mine. Test results indicate that the Secondary Aquifer has relatively low effective hydraulic conductivity (K). Low K in the Secondary Aquifer results in:

- Slow (*c.*0.1 m/d) horizontal and vertical groundwater flow, except where there is preferential flow along structures such as unconformities, faults, fractures and dyke intrusions;
- Limited groundwater storage;
- Potential for groundwater mounding below leachate sources if there is a high seepage rate; and
- Slow contaminant transport via advection (except along structures).

An unconformity separates the Vanrhynsdorp Group and NMC (Figure 2-6). The contact zone in the vicinity of the unconformity may form a preferential pathway of leachate towards the Sout River, due to the likelihood of fractures and associated higher local hydraulic conductivity values.

Deep groundwater levels (>40 mbgl) dominate most of the East Mine, thus groundwater users target the Secondary Aquifer for abstractions. The Secondary Aquifer generally has low to medium yields which range from 0.1 to 0.5 L/s (DWAF, 2005), however targeted fractures (comprising of the NMC meta-sediments) have higher yields ranging from 0.5 to 2.0 L/s (DWAF, 2005).

3.2 Groundwater Levels

Groundwater Levels and Flow Directions

Regionally, the water table contours mimic topography (i.e. higher lying terrain has elevated groundwater levels and vice versa). Groundwater levels vary between 1 and 414 mamsl between the coastline and hills in the east respectively (see Figure 3-1). Groundwater levels tend to be deep (>40 mbgl) for most of the EOFS Mine, within the saturated primary/sand aquifer overlying the bedrock. Low-lying areas (near the coast) have a lower hydraulic gradient (flatter), thus groundwater movement will be slower than further inland.

A groundwater divide exists between quaternary catchments F60D and F60E, which runs through the middle of the EOFS Mine (Figure 2-6). Groundwater north of the divide flows inland towards the Sout River and Groot Goeraap River, whereas groundwater south of the divide flows towards the coast and the Sout River.

Shallow groundwater levels are present near the coastline and river channels. Although shallow, most of the subsequent drainage takes place a few metres below the riverbeds. It is therefore assumed that the direct groundwater baseflow contribution to flow in the rivers is minimal. This is common in a semi-arid region with low rainfall and high evaporation.

It is assumed that hydraulic groundwater-surface water interaction only occurs during flooding/surface flow conditions (SRK, 2014). The deeper ground water levels are associated with the quaternary catchment divide in the study area (see Figure 2-6).

Recharge to the Groundwater Table

The study area has a low groundwater recharge from rainfall. Recharge ranges from 2.2 to 2.5 mm/a in the north, 0.4 to 0.6 mm/a in the middle, and 0.8 to 1.2 mm/a along the coastline (DWA, 2005). Lowest recharge occurs along the ridgeline between the Groot and Klein Goeraap Rivers and the higher escarpment in the north-east, with estimated values of 0.2 to 0.4 mm/a.

Existing operations of the TMS mine (West Mine, East Mine, processing plants, satellite sites etc.) contribute to recharge. Process water (primarily seawater in tailings) from these facilities, infiltrates through the geological horizons and enters the water table (recharge).

The site has generally low recharge rates with deeper groundwater levels, due to minor volumes of water percolating to the water table. This results in a reduced speed of natural attenuation by dilution, which may reduce the contaminant plume footprint.

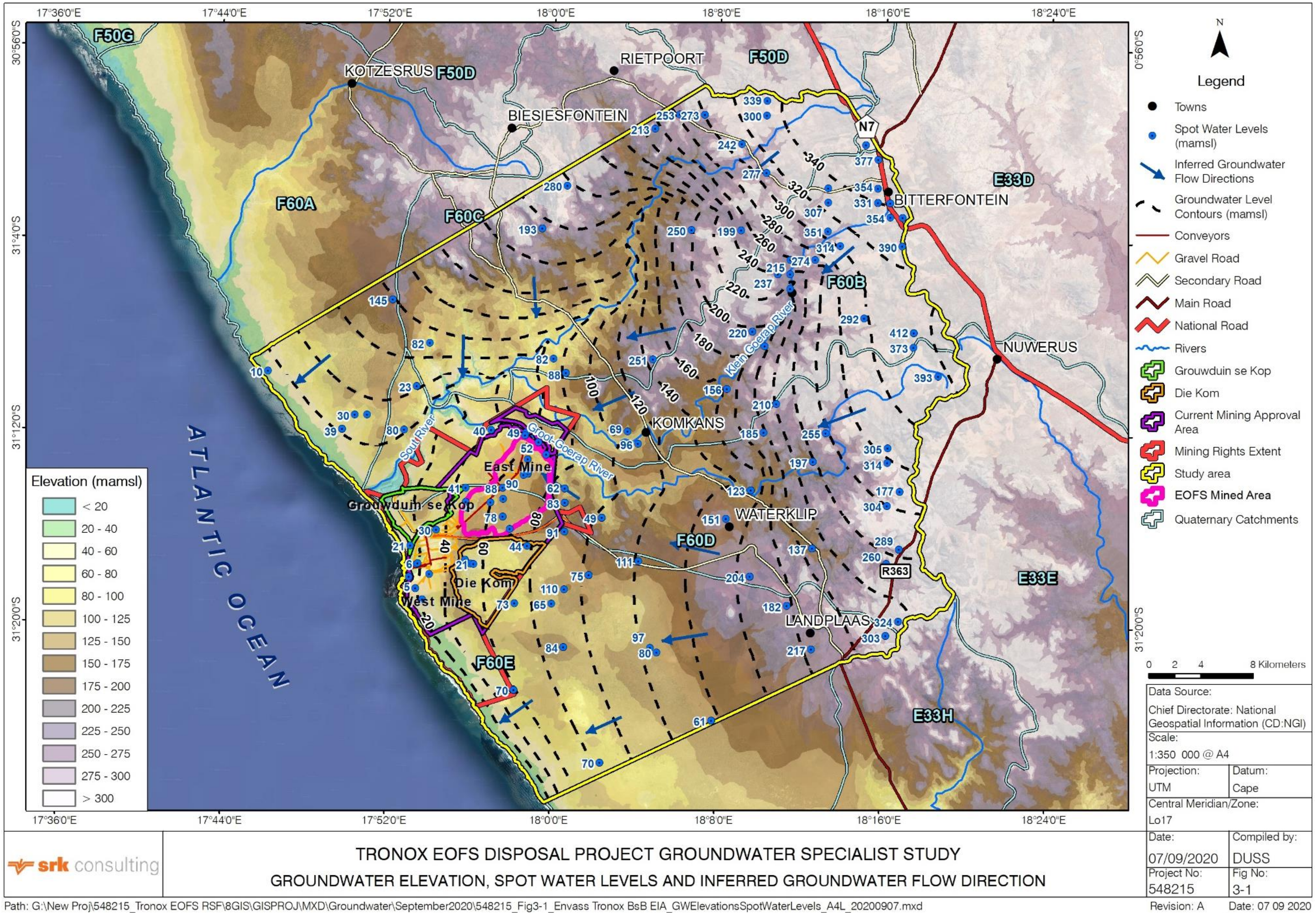

Figure 3-1: Groundwater Elevation, Spot Water Levels and Inferred Groundwater Flow Direction

3.3 Groundwater Quality

The electrical conductivity (EC) of groundwater in the study area ranges between *c.*600 to 1 500 mS/m, with a mean of *c.*1000 mS/m. Spatially, EC within the study area displays high concentrations that decrease towards the higher lying terrain further east (Figure 3-2). The central study area is characterised by intermediate concentrations, ranging from 840 to 1500 mS/m. This may be a result of both evapotranspiration, naturally high salt content in the local geology and previous backfill of saline material. This area also correlates to the lower hydraulic gradients where groundwater movement will be slower than further inland and towards the coast.

The borehole network datasets indicate that the EC exceeds the drinking water limit of the South African National Standard (SANS) 241:2011 (≤170 mS/m) by a considerable margin. According to the SANS 241 (2011) guidelines, the groundwater at the site is saline and not suitable for potable use.

The pH of groundwater in the area ranges between 6 and 9, with an average of 6.2, indicating slightly acidic water quality within the area.

3.4 Groundwater Users

The most recent hydrocensus was conducted by SRK in May 2019, when 35 boreholes within *c.*5 km of the mine site were surveyed. Of these,28 were identified and located and seven are no longer in existence as they were destroyed due to changes in the TNS Mine landscape.

The hydrocensus identified three main local receptors, including: groundwater, surface water and surrounding private borehole users and the following observations were made:

- The TMS mine is bordered by five neighbouring farms, namely Voorspoed Farm, Graauw Duinen 152, Rietfontein EXT 151, Kalkvlei and Hartebeeste Kom. These farms have 16 boreholes in total (Table 3-1), of which only one was accessible, open and in good condition to sample during the hydrocensus ('Grauww Duinen BH1'): however, the borehole was confirmed to be dry. The majority of the boreholes were in bad condition, as they had collapsed or were damaged.
- Groundwater is not suitable for human consumption (as discussed in Section 3.3), however relatively low volumes of groundwater are used for agricultural purposes (stock watering) in the region. The hydrocenus indicated that only six boreholes are used for this purpose near the Mine. These boreholes are all situated upstream of the site, and previous studies (SRK, 2019 and SRK, 2016) have indicated that they will not be affected by the project.
- The Cawood Salt Works Mine (located to the northwest of the TNS Mine) in the Sout River, was identified as a groundwater user and receptor. This mine abstracts groundwater (and surface water) and pumps it to the salt pans/evaporation ponds as part of their mining process. The evaporation process may concentrate the salts and contribute to salinization of the Sout River; and
- The Groot Goeraap and Sout River (discussed in Section 2.5) are the main surface drainage features in the area.

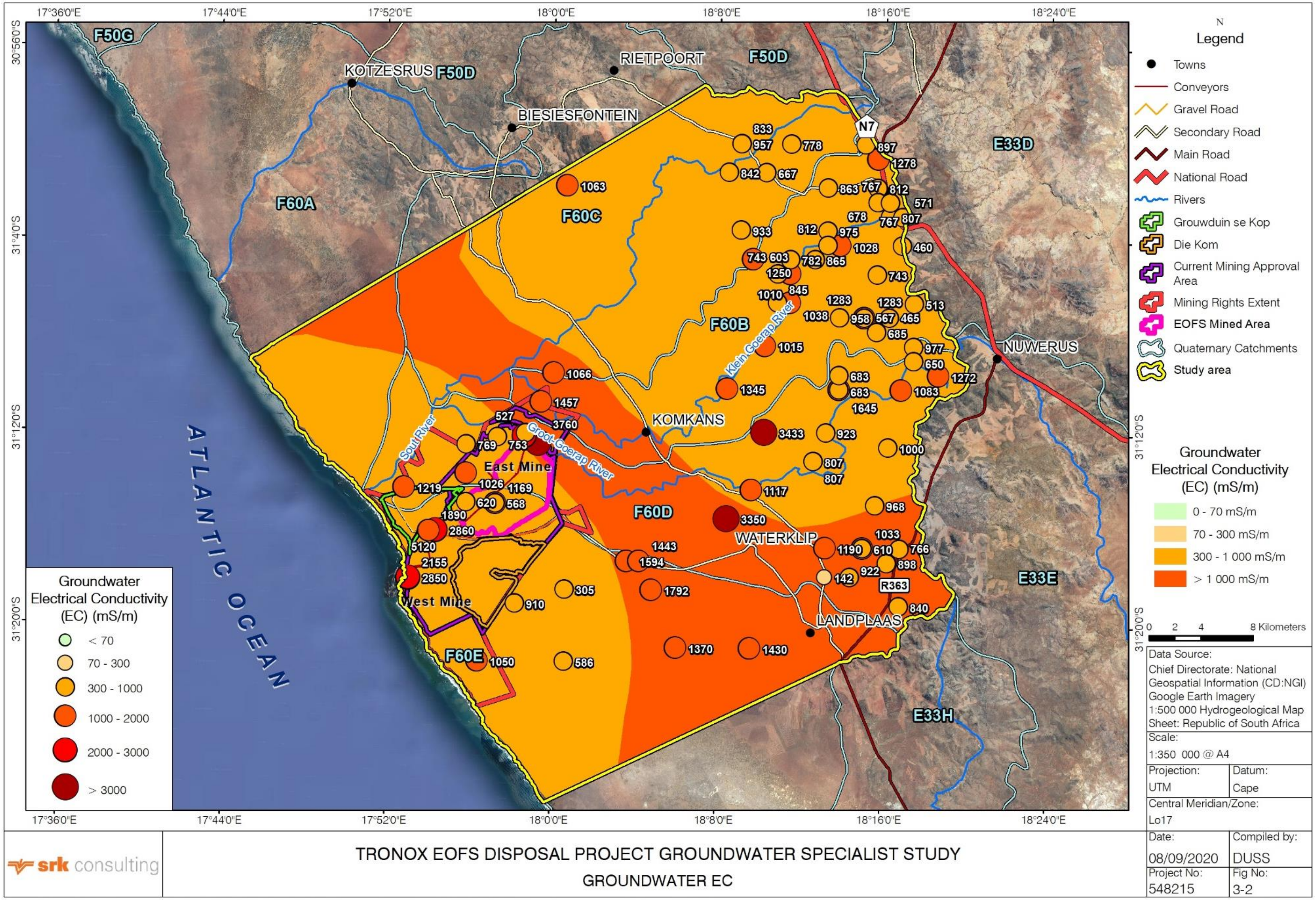

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Figure 3-2: Groundwater EC (mS/m)

Table 3-1: Hydrocensus Summary

Borehole ID	Farm Name	Latitude S	Longitude E	Owner	BH Depth (mbgl)	Casing Type/ Diameter (mm)	Water Level (mbgl)	Collar Height (magl)	Yield (l/s)	EC (mS/m)	pH	Temp ˚C	Remarks/ Comments
B1	Tronox Mine	31.29281	17.88409	Tronox	N/A	uPVC165	6.72	0.35	NA	>2 000	6.8	20.4	Mon. BH
GNS 1	Tronox Mine	31.20150	17.97830	Tronox	32.90	uPVC165	8.45	0.1	N/A	>2 000	7.63	22.1	Mon. BH
GNS 2	Tronox Mine	31.20340	17.97760	Tronox	24.31	uPVC165	19.81	0.52	N/A	>2 000	7.68	22.5	Mon. BH
GNS 3	Tronox Mine	31.20811	17.98841	Tronox	N/A	uPVC165	4.02	0.28	N/A	>2 000	7.75	22.2	Mon. BH
GNS 4	Tronox Mine	31.21655	17.99468	Tronox	10.80	uPVC165	7.29	0.4	N/A	>2 000	7.7	22.6	Mon. BH
GNS 8	Tronox Mine	31.26942	17.87706	Tronox	31.42	uPVC165		0.26	N/A	>2 000	7.07	22.2	Mon. BH
GNS 9	Tronox Mine	31.28037	17.88560	Tronox	50.08	uPVC165	17.11	0.2	N/A	>2 000	6.98	21.9	Mon. BH
GNS11	Tronox Mine	31.30223	17.88450	Tronox	43.45	uPVC165	12.37	0.3	N/A	>2 000	8.16	20.8	Mon. BH
GNS 11S	Tronox Mine	31.30235	17.88453	Tronox	15.04	uPVC165	12.71	0.48	N/A	>2 000	7.19	21.2	Mon. BH
GNS 12	Tronox Mine	31.25032	17.95430	Tronox	46.32	uPVC165	42.19	0.52	N/A	>2 000	7.91	22.5	Mon. BH
GNS 13	Tronox Mine	31.25041	17.95438	Tronox	63.40	uPVC165	42.92	0.4	N/A	>2 000	7.84	22.9	Mon. BH
GNS 14	Tronox Mine	31.26929	17.90634	Tronox	70.14	uPVC165	30.59	0.15	N/A	>2 000	7.49	21.4	Mon. BH
Voorspoed BH1	Voorspoed Farm	31.25471	18.01265	Piet Pool	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NU
Graauw Duinen BH1	Graauw Duinen 152	31.32349	17.88894	N/A	21.54	148	Dry	0.34	N/A	N/A	N/A	N/A	NU

Borehole ID	Farm Name	Latitude S	Longitude E	Owner	BH Depth (mbgl)	Casing Type/ Diameter (mm)	Water Level (mbgl)	Collar Height (magl)	Yield (l/s)	EC (mS/m)	pH	Temp ˚C	Remarks/ Comments
Rietfontein BH	Rietfontein EXT 151	31.23739	17.93180	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NU / D
Saltpan BH1	Rietfontein EXT 151	31.24213	17.88062	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	U
Kalkvlei BH1	Kalkvlei	31.30806	18.01831	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NU / D
Kalkvlei BH2	Kalkvlei	31.31545	18.01594	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NU / D
Kalkvlei BH3	Kalkvlei	31.32571	17.98887	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NU / D
Kalkvlei BH4	Kalkvlei	31.32054	17.97834	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NU / D
Kalkvlei BH5	Kalkvlei	31.29331	17.98359	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NU / D
Die Kom BH1	Hartebeest e Kom	31.29333	17.93675	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NU / D
Die Kom BH2	Hartebeest e Kom	31.29330	17.93456	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NU / D
Die Kom BH3	Hartebeest e Kom	31.31872	17.95363	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NU / D
Die Kom BH4	Hartebeest e Kom	31.29303	17.97646	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NU / D
Die Kom BH5	Hartebeest e Kom	31.28439	17.98574	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NU / D
Die Kom BH6	Hartebeest e Kom	31.28144	17.98730	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	NU / D

Note: Source – *SRK 2019 hydrocensus*

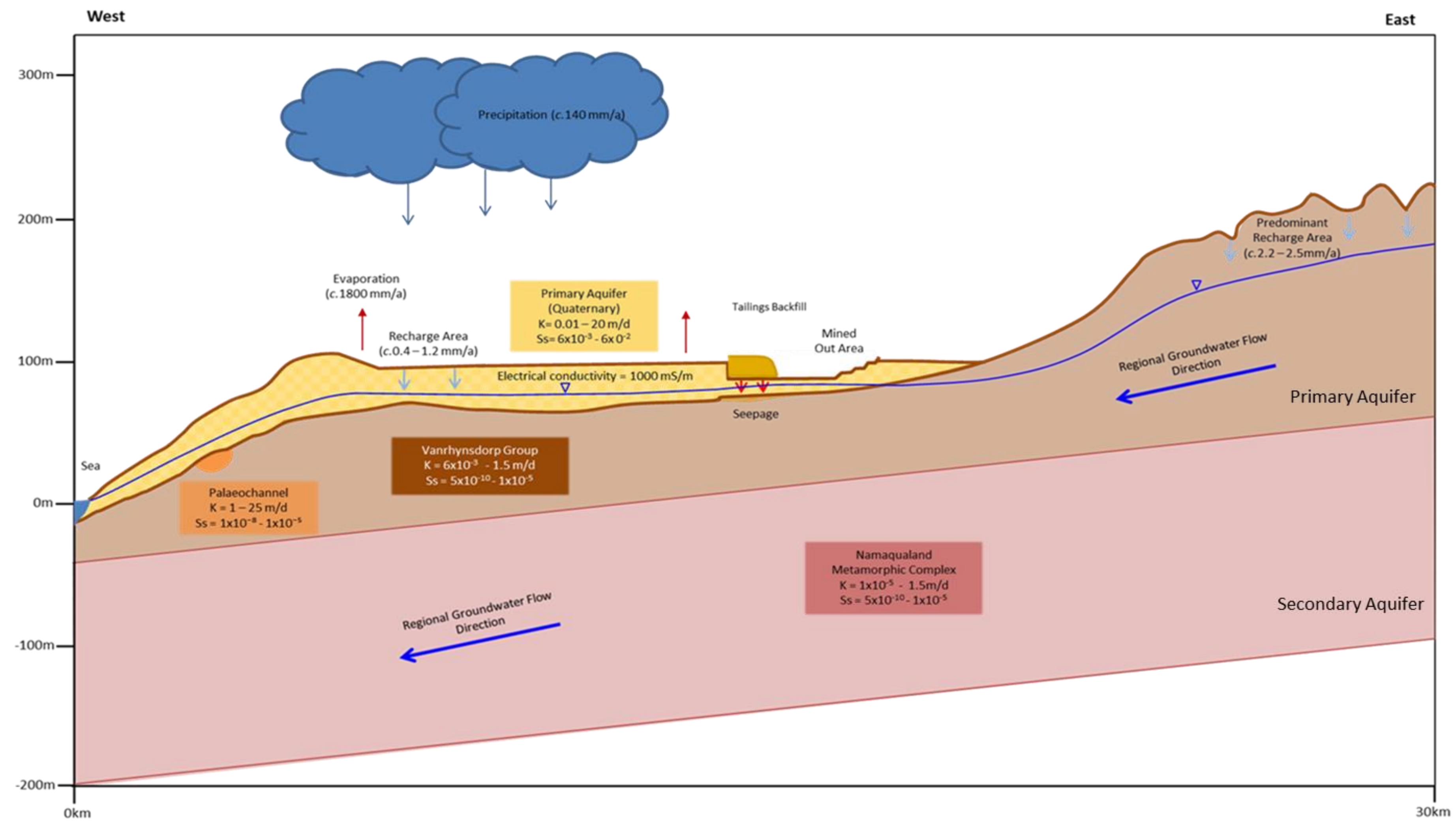
4 Conceptual Model

A conceptual geohydrological model is a descriptive representation of a groundwater system that incorporates an interpretation of the geological and hydrological conditions. It consolidates the current understanding of the key processes of the groundwater system, including the influence of stresses, and assists in the understanding of possible future changes.

4.1 Baseline Hydrogeology

The conceptual factors which influence the distribution and movement of groundwater are presented in Figure 4-1 below. The main concepts are summarised below:

- The study area is arid with an annual average rainfall of *c.*140 mm/a. Recharge in the study area occurs mainly on the high lying terrain in the east and ranges from 2.2 to 2.5 mm/a in the north to 0.4 to 1.2 mm/a along the coastline. The average evaporation rate over the study are is *c.*1 190 mm/a;
- The study area is located in a winter rainfall area with *c.*70 per cent of the precipitation occurring between April and September;
- Regionally, the water table contours correlate to topography. A groundwater divide exists between quaternary catchments F60D and F60E. North of the divide groundwater flow is directed inland towards the Sout River and Groot Goeraap River, whereas south of the divide groundwater is directed towards the coast;
- Water levels average *c.*>40 mbgl at the EOFS mine and are shallower near the rivers and coast;
- The unconsolidated/semi-consolidated sediments overlying the bedrock form the primary (intergranular) aquifer (*c.*<50 mbgl) in the study area. The Primary Aquifer has suspected preferential pathways for the spread of contaminants;
- Both intergranular and fractured aquifers are present in certain areas of the study area and are associated with the Quaternary sediments, the Vanrhynsdorp Group sediments, the NMC and the KFC formations. The higher yields are generally associated with geological structures such as faults, fractures, and dykes that form conduits or preferential pathways for groundwater flow. The matrix hydraulic conductivity (K) of these rocks is generally very low;
- The two aquifer systems are hydraulically connected. The Secondary Aquifer (*c.*>50 mbgl) is recharged by the Primary Aquifer and inland lateral recharge;
- Aquifer hydraulic properties have been estimated through various hydraulic tests and previous model calibration. The hydraulic conductivity values for the Primary Aquifer ranges from 0.01 to 20 m/d depending on the geology. Underlying this formation is the Vanrynsdorp Group bedrock which obtains a hydraulic conductivity value ranging from $6x10^{-3}$ to 1.5 m/d. The bedrock consists of the Namaqualand Metamorphic Complex which has a hydraulic conductivity ranging from $1x10^{-5}$ to 1.5 m/d; and
- Aquifer specific yield values have been estimated through hydraulic tests and previous model calibrations. The specific yield for the quaternary/Primary Aquifer ranges from $6x10^{-3}$ to $6x10^{-2}$. The underlying Vanrhynsdorp Group and Namaqualand Metamorphic Complex obtains a specific storage that ranges from $5x10^{-10}$ to $1x10^{-5}$.



srk consulting	**East OFS Project Residue Disposal Plan - Groundwater Specialist Study** Hydrogeological Conceptual Model	Project No. 548215

Figure 4-1: Hydrogeological Conceptual Model

4.2 Mine Operations

Tronox Mine is split into the East and West Mine (referred to in Section 1.1). The East Mine is currently a shallow mine, where mining of only the top RAS layer occurs.

Current operations

Currently only the surface RAS is mined in the East Mine to a maximum depth of about 6 m up to 2024, using a conventional open pit panel mining method (excavation). Tailings are returned from the PCP East by the dual carry conveyor to branch conveyors and grizzly feeders for pit backfilling. Fine residue from the PCP East is pumped to the active East Mine RSF (currently East Mine RSF 5). The pit of each mining block is backfilled it is profiled/shaped, and windbreaks are installed. Harvested topsoil is then spread in rehabilitated areas which are monitored to determine rehabilitation success.

Proposed East-OFS operations

Tronox is authorised to mine the deeper OFS resource underlying the RAS material to a depth of 35 m, however it is likely that mining will only take place to a depth of *c.*7 m on average, due to the economic viability of the ore grade. This project is known as the EOFS Project (study area) as seen in Figure 4-2 below.

For the EOFS Project to proceed, Tronox must modify the approved residue disposal plan which entails the additional proposed infrastructure (Figure 4-2) and activities.

This entails a single RSF to accommodate all fine residue from the project (as opposed to three smaller RSFs as per the current EOFS Project authorisation), changes to the backfill operation into shallow deposition areas and deeper deposition and "building" of STFs):

- RSF:
    - Establish a *c.*400 ha, *c.*39.6 million m^3 (volumetric capacity) RSF (known as RSF 6) for the controlled disposal of fine residue generated by the East OFS project (as opposed to three separate, smaller fine residue facilities which were approved in the original application) and associated residue and return water pipelines and pumps. The walls of the facility will be a maximum of 20 m high and will be built at a slope of 26.6^o.
- Shallow and deep depositional areas (STFs)
    - Change the backfill operations into shallow deposition and deeper deposition in STFs)in the East Mine pit to accommodate the surplus sand tailings from, but not all backfilled to, the void in the pit. Each stockpile will be a maximum of *c.*14 m high *(c.*12 m above the post mining ground level, and *c.*7 m above the current ground level – see Figure 4 3);
    - STF 1 will have a footprint of *c.*290 ha and a length and width of 1 700 m, at the location indicated in Figure 4-2; and
    - STF 2 will have a footprint of *c.*250 ha and a length of 1 900 m and a width of 1330 m, at the location indicated in Figure 4-2.
- Mine void backfill:
    - The EOFS mine pit will be backfilled with 1 m of tailings throughout the mined-out area.
- Overburden Stockpile:
    - Establish a 50 ha Interim Overburden Stockpile with a capacity of 3.15 Mm^3 in an area approved for mining east of the proposed RSF; and
    - Deposit overburden at a maximum height of 5.6 m above ground level.

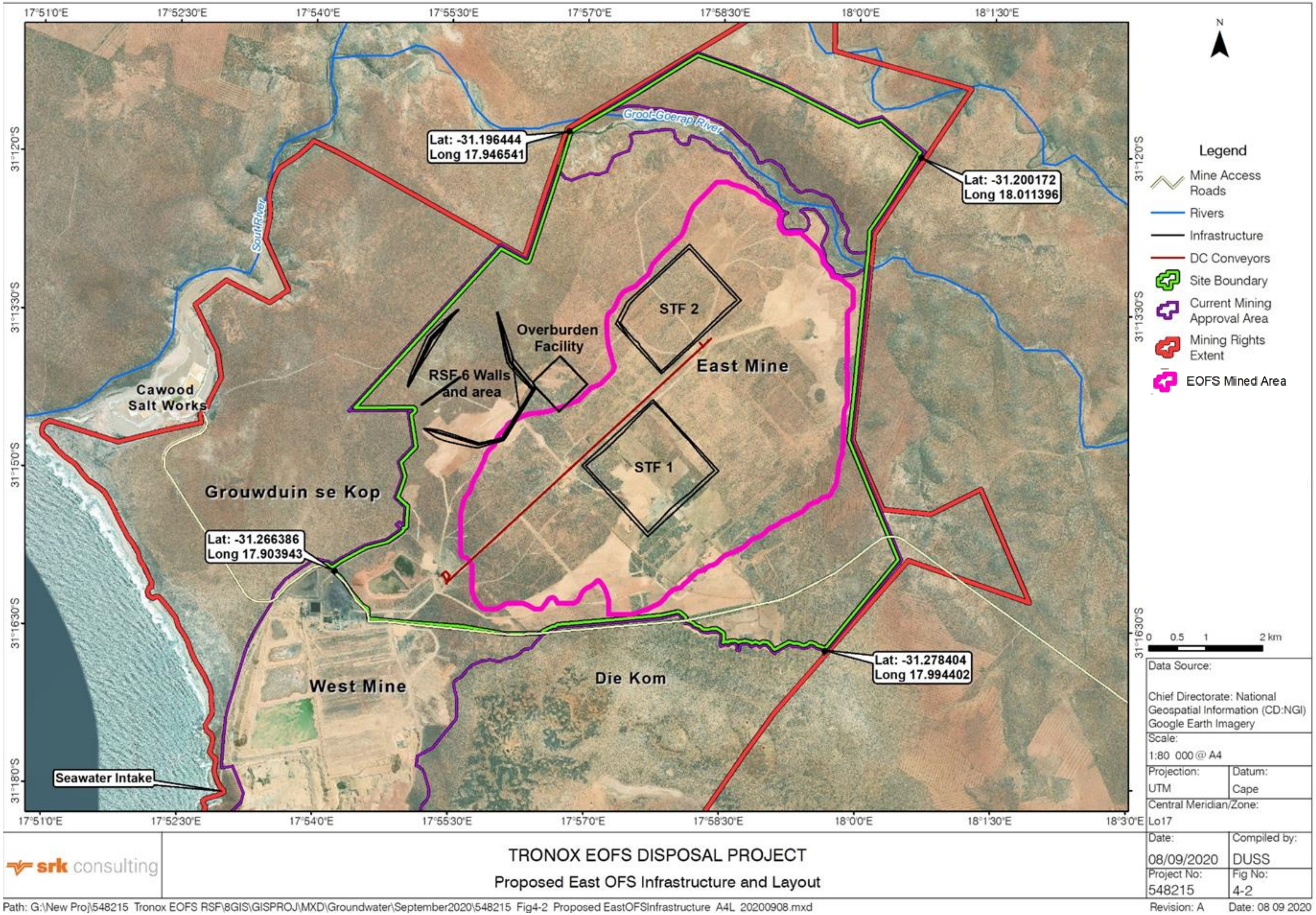
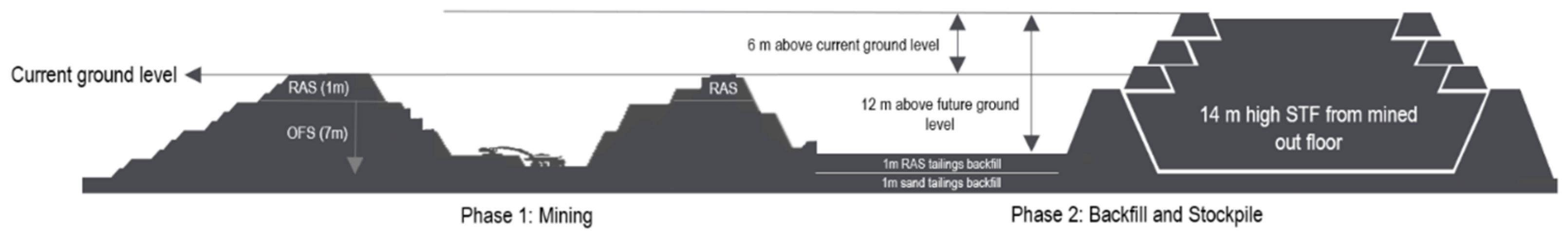


Figure 4-2: Proposed East OFS Infrastructure and Layout



srk consulting	**East OFS Project Residue Disposal Plan - Groundwater Specialist Study** Schematic of EOFS sand tailings disposal	Project No. 548215

Figure 4-3: Schematic of EOFS Sand Tailings Disposal

5 Numerical Groundwater Model

5.1 Objective

The objective of the numerical groundwater model is to assess the potential hydrogeological impacts from the EOFS Project for various scenarios. This is achieved through:

- Identification and simulation of mining voids and seepage to groundwater from potential contaminant sources of the EOFS project (RSF, Tailings (shallow areas and deep depositional STFs), Overburden Stockpile and mine void backfill);
- Use of an existing calibrated groundwater model to simulate the likely pathway for contaminant transport (described in Sections 5.2 to 5.6); and
- Assessment of potential water quality and quantity degradation to identified receptors (including local aquifers, surface water (due to interactions with groundwater) and private boreholes users (Section 5.7).

5.2 Model Approach

The groundwater model was formulated in three-dimensions (3D) to simulate groundwater movement in both the horizontal and vertical planes. A professional graphical interface, Groundwater Vistas, developed by Environmental Simulations, Inc, (Rumbaugh and Rumbaugh, 2000), was used to create the model input data sets and to analyse and display the modelling results. The model was constructed using Groundwater Vistas Version 7 (GVW7), a pre- and post- processing package for the modelling code MODFLOW-USG. MODFLOW-USG (Panday et al., 2013) advanced version and the xMD solver for unstructured grids were used in the simulation of hydrogeological responses for the various contaminant transport scenarios.

MODFLOW-USG is based on an underlying control volume finite difference (CVFD) formulation in which a cell can be connected to an arbitrary number of adjacent cells. MODFLOW–USG includes a Groundwater Flow (GWF) Process, based on the GWF Process in MODFLOW–2005. MODFLOW-USG provides a framework for tightly coupling multiple hydrologic processes. The tight coupling occurs through the formulation of a global conductance matrix that includes the cells for all processes. The framework allows individual MODFLOW–USG processes to add to the global conductance matrix to represent fluxes between cells within a process as well as with cells of other processes. The global conductance matrix can be symmetric or asymmetric and is unstructured, indicating that an individual cell may have an arbitrary number of connections with other cells. The CVFD formulation accommodates this unstructured framework of tightly coupling flow processes as well as of allowing flexibility in cell geometry and connectivity within processes. Following is the general form of a CVFD balance equation for cell n:

$$\Sigma_{m\epsilon n}\, C_{nm}\,(h_m - h_n) + HCOF_n\,(h_n) = RHS_n$$

Where:

- C_{nm} is the inter-cell conductance between cells n and m
- h_n and h_m are the hydraulic heads at cells n and m
- $HCOF_n$ is the sum of all terms that the coefficients of h*n* in the balance equation for cell n, and
- RHS_n is the right-hand-side of the balance equation

Listed below are a few reasons why MODFLOW was selected as the modelling package and more specifically Groundwater Vistas as the graphical interface:

- It simulates steady and non-steady state flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination thereof;
- Flow from external stresses such as flow to boreholes, aerial recharge, evapotranspiration, flow to drains and flow through riverbeds, can be simulated;
- Hydraulic conductivity or T for any layer may differ spatially and be anisotropic;
- The storage coefficient may be heterogeneous;
- Internationally, it is currently the most used numerical model for flow problems; and
- The MT3D mass transport package runs together with MODFLOW. This facilitates simulation of the transfer of solutes within the groundwater flow model.

Post processing was completed using ESRI ArcGIS and MS Excel spreadsheets.

5.3 Assumptions and Limitations

The following assumptions were taken during the development of the groundwater numerical model:

- The diffusion co-efficient was set to 10^{-9} m^2/s (9×10^{-4} m^2/d) (Appelo and Postma, 2005);
- A longitudinal dispersivity value of 100 m was selected for the simulations (Spitz and Moreno, 1996);
- An average value of 10 m was selected for this parameter for the simulations (noting that Bear and Verruijt [1992] estimate that the average transverse dispersivity is 10 to 20 times smaller than the longitudinal dispersivity);
- As no abstraction data is available for Cawood Salt Works, it is assumed that the abstractions from Cawood Salt Works do not influence groundwater as they are close to the Sout River recharge boundary; and
- Groundwater Resource Assessment II (GRAII) developed by the Department of Water Affairs and Forestry (2005) was used to estimate of the recharge of over the study area, thus it is assumed that recharge over the area is representative of these values.

The following limitations of the model are noted:

- A limitation of MODFLOW is the simulation of flow in specific fracture zones. Such zones exist within the study area, but at the scale of the regional and scenario modelling, it is considered that MODFLOW will provide adequate representation of the system response;
- Numerical groundwater models are very useful tools for assisting in the simulation and prediction of groundwater movement under proposed scenarios. They are always theoretical, however, and only based on available data and therefore careful interpretation of the results and regular update of the model is required to draw the most informative conclusions.

5.4 Model Construction

5.4.1 Finite Difference Network

The numerical flow model boundary is equivalent to the study area (Figure 2-1), which includes the quaternary catchments F60A, F60B, F60C, F60D and F60E. The study area follows the quaternary catchments in the east and the coastline in the west. In the north and south, the study area boundary runs parallel to the assumed groundwater flow direction.

The model grid was rotated 31º clockwise so that it is aligned with the regional flow direction (north-east to southwest towards the coast). Grid rotation is a standard practice in finite difference groundwater models and simplifies the process of grid discretisation in and around linear features, expected flow directions and anisotropic hydraulic parameters.

The total area covered by the finite difference grid is approximately 2 021 km^2 (47 km x 43 km, comprising 238 rows and 256 columns). Within the grid, there are 2 550 275 active modelling cells, resulting in an active model area of approximately 1 921 km^2. On the mine site, model cells are set to a dimension of 25 m x 25 m, increasing in size away from the Mine to a regional model cell dimension of 200 m x 200 m. The coordinates for the model origin (lower left corner) are - 95 019, - 3 486 378 (in co-ordinate system LO 17, Clarke 1880).

The site is underlain by unconsolidated and semi-consolidated sediments of Quaternary age. These sediments overlie meta-sediments of the Vanrhynsdorp Group, the metamorphic rocks of the NMC, as well as granites and dykes of the KF*C.*

The top elevation of the natural terrain was assigned to topography by importing the GIS shape file for the 20 m x 20 m Digital Elevation Model (DEM) of the area. The post-mining topography of the EOFS (RSF's, tailings (shallow areas and deep depositional STFs) and Overburden Stockpile) was incorporated via Drawing Interchange Format (DXF) files. The saturated thickness of the primary and Secondary Aquifers was assumed to be approximately 200 m, based on Groundwater Resource Assessment Phase 2(GRAII) estimates for the quaternary catchment, knowledge of the area as well as Light Detection and Ranging (LIDAR) data collected at RSF 6. The model is subdivided into seven layers, of which the top five are associated with the Primary Aquifer and the bottom two are associated with the Secondary Aquifer.

The EOFS mine area has been significantly transformed through surface mining activities via the construction of large man-made landforms, namely the RSFs, STFs, mine void and Overburden Stockpile. These topographical changes have been carefully considered and accounted for in the model. Descriptions and conceptualisation of the model layering are provided in Table 5-1 and Figure 5-1 (not drawn to scale) below.

Table 5-1: Modelled Topography

Layer	Natural topography (Around the EOFS mine site)	Altered topography (Within the EOFS mine site)
1 & 2	Natural Topography	Post-mining topography of the facilities (RSF, shallow areas and deeper depositional STFs, and Overburden Stockpile)
3	Mimic natural topography of Layer 2	Mined-out floor +0.3m (Base preparation layer for scenario analysis).
4	Vanryhnsdorp geological formation which surfaces at 0 mamsl at the coast, extends to *c.*30 mamsl across East RSF 6 and crops out towards the higher lying elevations in the east.	Mined-out floor
5	Vanryhnsdorp geological formation continued	
6 & 7	Namaqualand Metamorphic Complex which is modelled as a planar surface dipping from the north-east towards the coast with a dip gradient of 0.004 (vertical drop / horizontal distance).	

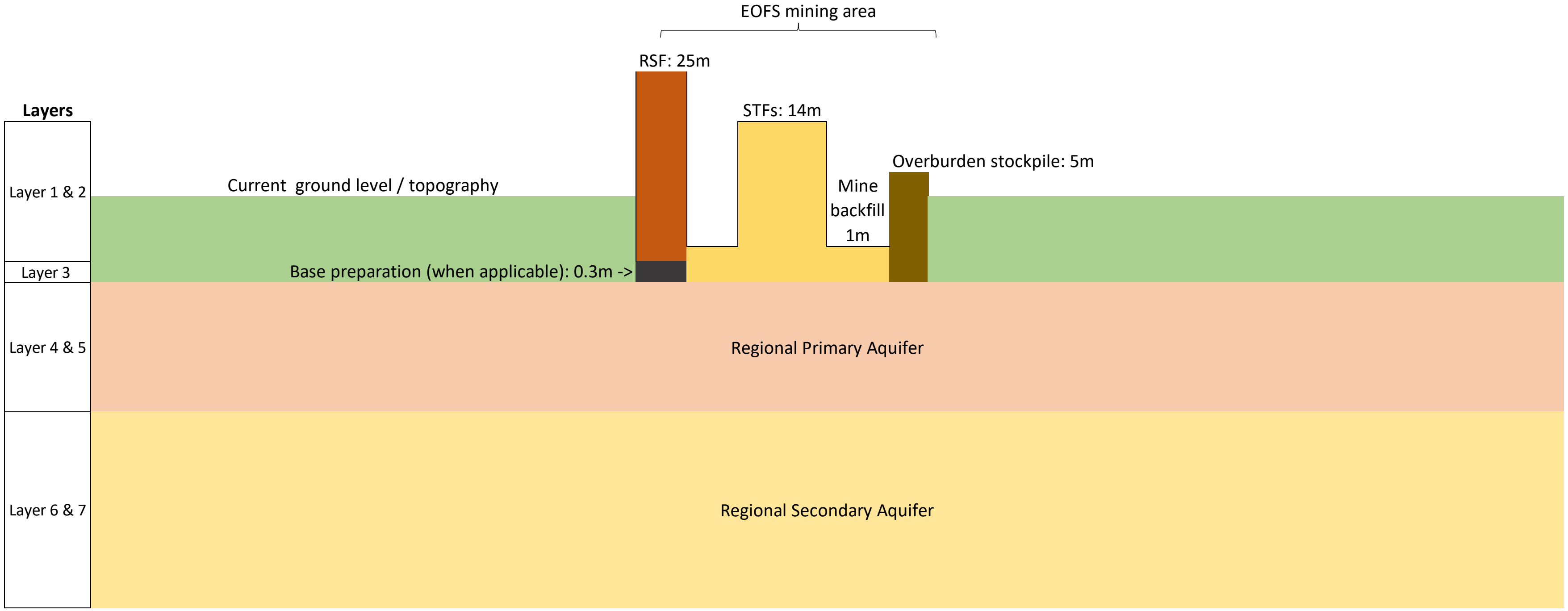


Figure 5-1: Model Layering

5.4.2 Boundary Conditions

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

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

Boundary conditions must be specified for the entire boundary and may vary with time. At a given boundary section just one type of boundary condition can be assigned. Boundaries in groundwater models can be specified as:

- Constant head or constant concentration boundary conditions;
- Neuman (or specified flux) boundary conditions; and
- Cauchy (or a combination of Constant and Neuman) boundary conditions.

The following boundary conditions were included in the model:

- All remaining boundary cells at the model edge are prescribed as **no flow** as they follow the quaternary catchment boundaries (and therefore assumed groundwater divide) in the east, and run parallel to the assumed groundwater flow direction along the northern and southern boundaries;
- The coastline on the west side of the study area is represented by a **constant head boundary** that maintains a water level of 0 mamsl; and
- All rivers and drainage channels were represented as **drains**, which effectively only allows for water into the stream and not out into the groundwater table, i.e. gaining stream. This boundary condition is active when groundwater levels are higher than the defined base of the river.

5.4.3 Sources and Sinks

Sources and sinks can be defined as recharge and abstraction sources in an aquifer.

Sources contributing to aquifer inflow include precipitation, backfill and deposited material. All sources are simulated as a recharge rate. Natural recharge rates were derived from the GRAII (DWA, 2005) which ranges from 0.4 to 2.5 mm/a. Sinks contributing to groundwater outflow are evaporation, groundwater discharge to surface water bodies (such as the Sout River and Groot Goeraap Rivers) as well as borehole abstraction from neighbouring properties. The borehole yields from farmers in the study area are very low and there is no data about the Cawood Salt Work Mine abstractions. Therefore, abstractions were not included in the model as the neighbouring farmers would have little/no significant impact on the aquifer

5.4.4 Aquifer Parametisation

Two main parameters are used to describe the physical hydraulic properties of the aquifer, namely storativity and hydraulic conductivity (K).

Storativity (S) is the volume of water per volume of aquifer released as a result of a change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness of the saturated porous medium. For an unconfined aquifer, the S is the ratio of the volume of water that drains by gravity to that of the total volume and is known as specific yield.

Hydraulic conductivity is a measure of a material's capacity to transmit water. It is the rate of flow under a unit hydraulic gradient through a unit cross-sectional area of aquifer.

Both K's and S's were obtained from pump test data analyses for previous studies (GCS, 1993a, GCS, 1993b - Rev2, SRK, 2015). In the finite difference method, geohydrological parameters are assigned to model cells or blocks, while hydraulic head and flow are attributed to their centre points. Each cell in the model therefore has an individual geohydrological domain code. The main hydraulic zones were subdivided based on specific geological formations (see Figure 2-6) and included in the model. The hydraulic properties of each zone are shown in Table 5-2 below.

Table 5-2: Aquifer Hydraulic Properties

Geohydrological Zone	Horizontal Kx and Ky (m/d)	Vertical Kz (m/d)	Specific storage	Specific Yield
Primary Aquifer (regional)	0.1	0.001	$1x10^{-5}$	0.01
Primary Aquifer (granitic soil)	0.02	0.002	$1x10^{-5}$	0.01
Bedrock, Vanrhynsdorp	0.03	0.003	$1x10^{-8}$	0.01
Bedrock, NMC	0.015	0.0015	$1x10^{-8}$	0.01
Preferential flow paths	0.07	0.007	$1x10^{-3}$	0.01
Gabbro dykes	0.001	0.001	$1x10^{-8}$	0.01
Faults	0.1	0.1	$1x10^{-8}$	0.01

No horizontal anisotropy (Kx versus Ky) was applied to the model. The low vertical to horizontal K values in the regional Primary Aquifer represents the retarding effect of the dorbank (calcrete) layer within the Primary Aquifer. These values were assigned based on a review of all available hydraulic properties data presented in the conceptual model and baseline study. The K and S values are within the range estimated in the conceptual model.

5.5 Model Calibration

Calibration of the groundwater model was undertaken and reported in the *'Phase 1 Geohydrological Assessment and Numerical Modelling for the Brand se Baai Mine Site'* study (SRK, 2015). Calibration was conducted using water levels of 390 NGA boreholes and 21 site boreholes. The calibration objective was reached when an acceptable correlation was obtained between the observed and simulated water levels and hydraulic gradient. The regional modelled versus observed water level data shows a correlation of 89 %. Water levels are only one of the calibration acceptance criteria. The full list of steady state acceptance criteria and model calibration results is shown in Table 5-4 below.

SRK has conducted numerous groundwater modelling studies at the Tronox Brand se Baai site, providing confidence in model calibration. These studies include:

- Baseline groundwater assessment and numerical groundwater model for the mine (SRK, 2014);
- Groundwater assessment and modelling of appropriate predictive scenarios for the northern and southern expansion to the mining rights, and all other areas within current mining authorisation that will be mined (SRK, 2015);
- Groundwater modelling for Slimes Dam 6 (SRK, 2016); and
- Hydrogeological Assessment for Die Kom and Grouwduin se Kop Expansion Areas (SRK, 2019).

Table 5-3: Steady State Model Calibration Acceptance Criteria

#	Modelling and Simulation Requirements	Acceptability Criteria	Model Results
1	Convergent	Head change criteria is within 0.001 m.	Head change criteria within 0.001 m. (This is the maximum absolute value of the head change for the iteration for each cell.)
	Well-balanced	Residual criterion is within 1 m^3.	Residual criterion is within 1 m^3. (This is the maximum absolute value of the difference between inflows and outflows for each cell.)
2	Well-balanced	Water Flow Mass Balance (inputs versus outputs) has an error less than 0.5%	Mass balance error = *c.*0.1%
3	Model cells don't go 'dry' and hinder vertical flow unnaturally	No dry model cells below the top active layer in the model. Dry cells in the top layer should correlate approximately with areas of likely unsaturation.	There are no dry cells in the model.
4	All pumping wells are able to pump to the historical volumes specified	Mass balance totals for well abstraction volumes should match 100% with the input historical abstraction volumes.	There are no modelled abstractions.
5	Long term groundwater flow directions correlate with the conceptual model	Qualitative check that the groundwater flow directions correlate with the conceptual model flow directions.	Water levels rise from 0 mamsl along the coast to 350 mamsl inland. The contours indicate that the predominant groundwater flow direction is towards the coast, with local flows towards the Sout and Groot Goeraap rivers. This is in keeping with the conceptual model.
6	Long term regional water levels correlate reasonably to observed data	80% of simulated regional water levels (multiple boreholes, often over different time periods and with few data points per site) are within 10 m of historical observations and/or a correlation of above 75% is achieved (where correlation is calculated as the square of the Pearson product moment correlation coefficient through data points). This acceptability criterion was selected by taking into account the variability of aquifer conditions and large number of data points (>100 boreholes) included in the calibration.	Regional target water level correlation = 89%
7	The losing and gaining of river baseflow correlates with the conceptual model, as well as any river flow data and observations available	Mass balance totals over zones in a river will show the volumes lost and gained from a river to groundwater. The expected lengths of river gain or river loss to groundwater should be in keeping with the conceptual model gains and losses over a minimum of 90 % of the river reaches, with actual volumes lost and gained not more than double or less than half of the volumes measured or calculated analytically at any particular location where historical baseflow data is available.	Steady state regional flow to the river drainage channels = *c.*4 000 m^3/d, and flow directly to the sea = *c.*1 700 m^3/d. There is no flow from the rivers to the groundwater. These values are in keeping with the conceptual model of low surface/groundwater interaction.

Note: Source – SRK, 2015 - *Phase 1 Geohydrological Assessment and Numerical Modelling for the Brand se Baai Mine Site*

5.6 Transport Processes

Mass transport modelling in this context refers to the simulation of water contamination or pollution due to deteriorating water quality in response to anthropogenic disturbance (e.g. mining) of the natural environment.

Transport through an aquifer medium is mainly controlled by the following:

1. Advection: This is the component of contaminant movement described by Darcy's Law. If uniform flow at a velocity V takes place in the aquifer, Darcy's law calculates the distance (x) over which a labelled water particle migrates over a time period t as x = Vt.
2. Hydrodynamic dispersion: This comprises two processes:
   - Mechanical dispersion is the process whereby the initially close group of labelled particles are spread in a longitudinal as well as in a transverse direction because of the velocity distribution (as a result of varying microscopic streamlines) that develops at the microscopic level of flow around the grain particles of the porous medium. Although this spreading is both in the longitudinal and transversal direction of flow, it is primarily in the former direction. Very little spreading can be caused in the transversal direction by velocity variations alone; and
   - Molecular diffusion mainly causes transversal spreading, by the random movement of the molecules in the fluid from higher contaminant concentrations to lower ones. It is thus clear that if V = 0, the contaminant is transported by molecular diffusion only or in other words the higher the velocity of the groundwater, the less the relative effect of molecular diffusion on the transportation of a labelled particle.

In addition to advection, mechanical dispersion and molecular diffusion, several other phenomena may affect the concentration distribution of a contaminant as it moves through a medium. The contaminant may interact with the solid surface of the porous matrix in the form of adsorption of contaminant particles on the solid surface, deposition, solution of the solid matrix and ion exchange. All these phenomena cause changes in the concentration of a contaminant in a flowing fluid.

5.7 Transport Parameterisation

The MT3D software was used to provide numerical solutions for the concentration values in the aquifer in time and space. The MT3D model uses data from the associated MODFLOW flow model, and in addition requires the following inputs:

- Chemical element to be modelled;
- Background concentrations of the contaminant;
- Source concentrations of the contaminant;
- Discharge/infiltration rate to groundwater;
- Kinematic porosity;
- Diffusion coefficients;
- Longitudinal dispersivity;
- Transversal dispersivity; and
- Partition co-efficient and bulk density (required for modelling sorbing contaminants).

5.8 Predictive Scenarios

Predictions of seepage to groundwater and contaminant plume footprints were made for two RSF designs, referred to as the *original RSF* design and the *revised RSF* design. The *original RSF* design was specified at the start of the study, premised on existing mine plans, whereas the *revised RSF* was based on the updated groundwater mass balance provided by the design engineers (Epoch) in November 2020.

5.8.1 Scenario Setup

The RSF, tailings backfill (shallow areas STFs) and Overburden Stockpile are the potential groundwater contaminant and seepage sources of the EOFS Project.

Tailings will be backfilled into the mine void in the pit (*c*.1 m spread) and the surplus tailings will be placed onto two new STFs, i.e STF 1 and STF 2 with an area *c.*290 ha and *c.*250 ha respectively (See Figure 4 2) and a material K of 2.5 x 10-5 m/s. Each stockpile will be a maximum of *c.*14 m high (c.12 m above the post mining ground level, and *c.*7 m above the current ground level).

The Overburden Stockpile with a K of 2.5 x 10-5 m/s will be built over 3 years covering an area of 50ha with a capacity of 3.15 Mm^3.

The~400 ha RSF is located north of the PCP East and on the northern boundary of the East Mine. The walls of the facility will be a maximum of 25 m high and the RSF material will have a K of 1×10^{-8} m/s.

The maximum volume of water/moisture deposited at the RSF, tailings (STFs and mine void) and Overburden Stockpile are assumed to be *c*.17 000, *c*.40 000 and *c*.3 600 m^3/d respectively, of which the majority evaporates or is pumped back into the process, but some seeps to groundwater.

Seawater will be used to process East OFS ore, and the beneficiation process will not require chemical processes or treatment (besides separation of material using a flocculant), thus the leachate quality is assumed to be primarily that of seawater (EC of c.5 000 mS/m). Natural background water quality in the area has a mean EC of *c*.1000 mS/m and ranges between *c*.600 and *c*.1 500 mS/m. This significantly exceeds the potable water standard of 150 mS/m indicating poor water quality.

The normalised percentage scale modelling method is used to represent: 1) contamination for all conservative elements and 2) worst case for all non-conservative elements. This method represents all concentrations as a percentage of source leachate concentration, whereby the source of leachate concentration is 100% and the background concentration is 0%.

Predictive numerical groundwater scenarios were undertaken to simulate the additional impacts of the EOFS Project on groundwater, including RSF base preparation design options required by the National Norms and Standards for the Disposal of Waste to Landfill (GN636 - promulgated in terms of NEM:WA). Following a risk-based approach, Tronox and their design engineers (Epoch) considered the following RSF base layer options/ scenarios:

- Scenario 1 (Sc1): "as is"/no base preparation: This scenario assumes that no base preparation is required for the RSF, thus the base layer is set to the same K as the RSF material itself *(c.*1 x 10^{-8} m/s);
- Scenario 2 (Sc2) – engineered base preparation. This scenario assumes there is base preparation for the RSF. Although considered as an option, this scenario was not numerically modelled as the compacted in-situ soils are unlikely to be any less permeable than the fine residue material, as noted by *Epoch:* "*Assuming an in situ soil of a sandy composition, local base preparation through compaction would unlikely decrease the permeability of this in situ material to a permeability lower than that of the fine residue material, assumed to have a permeability of approximately 1e-08 m/s.*

However, laboratory test work on the in-situ soils will confirm this assumption." (pers. comm. Kyle Liesker, email 14 August 2020);

- Scenario 3 - liner. This scenario assumes a Class C type liner as designed by the *Epoch* design engineers, who calculated two different 'equivalent K' values for the 0.3 m composite base, as follows:
  - Scenario 3a (Sc3a): A "reasonable" Class C (HDPE and CCL) installation, represented by an equivalent 0.3 m thickness with K = 5.13 x 10^{-9} m/s; and
  - Scenario 3b (Sc3b): An "excellent" Class C (HDPE and CCL) installation, represented by an equivalent 0.3 m thickness with K = 1.47 x 10^{-10} m/s.

Predictive scenarios were run for the two RSF designs, namely the *revised RSF* and *original RSF*. As mining and backfilling have been underway for many years at the site, the assumed 2020 conditions (water levels and concentrations) are set to those previously modelled (SRK, 2019). Figure 5-2 shows the modelled active seepage times for the infrastructure facilities, the location of which is shown in Figure 4-2.

Post-mining predictive scenarios cover a period of 100 years, with outputs at 20, 50- and 100-years post-closure (2070, 2100 and 2150). During post-mining the model takes on the assumption that the deposited material over the RSF, Tailings (shallow areas and STFs) and Overburden Stockpile have reduced in permeability and consolidate, causing a reduction in K by *c.*40% (Slimes Dam Study – SRK, 2016).

The following assumptions and parameters (Table 5-4) were used to create the flow and transport models:

- EOFS mining depths are as provided by Tronox (pers. comm. Andre de Beer, 2 July 2020);
- The mine tailings backfill schedule (including the entire mined out area and the deep and shallow mining deposition areas) are as provided by Tronox (pers. comm. Andre de Beer, 2 July 2020);
- It is assumed that non of the backfilling areas will be lined;
- The depositional rate of the Overburden Stockpile is equivalent to its capacity divided by the number of years active *(c.*3.15 Mm^3/ 3 years = *c.*1.05 Mtpa);
- Potential water available (applied at surface) of the RSF, backfilled mine void / STFs, and Overburden Stockpile is calculated using depositional rate, moisture content and number of years active;
- Seepage from the facility into groundwater is dependent on evaporation, pumping of seepage water and the hydraulic properties of the material and base layer;
- Engineered base layers have hydraulic properties defined by Epoch (*pers. comm.* Kyle Liesker, email 12 August 2020);
- Seepage is assumed to continue for five years post cessation of deposition with a continued concentration of 100% but a decreasing recharge rate down to background recharge (from rainfall);
- The diffusion co-efficient was set to 10^{-9} m^2/s (9 x 10^{-4} m^2/d) (Appelo and Postma, 2005);
- A longitudinal dispersivity value of 100 m was selected for the simulations (Spitz and Moreno, 1996);
- The moisture content of the Overburden Stockpile is 5%, as advised by the Design Engineers (Epoch);

- An average value of 10 m was selected for this parameter for the simulations (noting that Bear and Verruijt [1992] estimate that the average transverse dispersivity is 10 to 20 times smaller than the longitudinal dispersivity);
- The simulation assumed no sorption (as for conservative elements), therefore the partition co-efficient and bulk density values were not required; and
- The maximum volume of seepage of water "available" is the volume of water which could percolate to the groundwater table from the RSF, i.e. the maximum volume of water remaining in the RSF after water has been returned to the process plant).

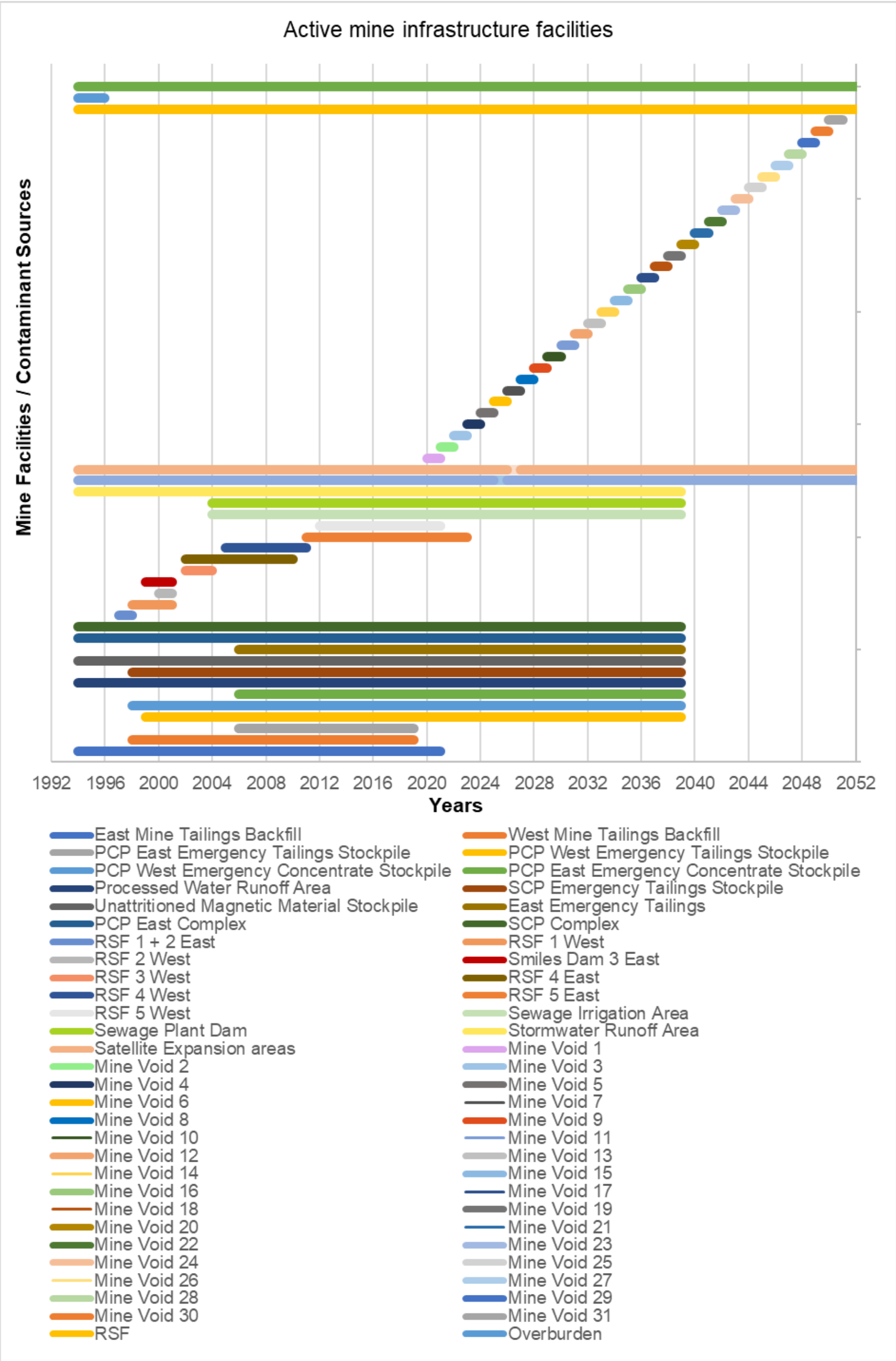


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Figure 5-2: Active Operational Facilities

Table 5-4: Scenario Parametisation

Parameter	Units	Original RSF	Revised RSF	Tailings (shallow areas and STFs)	Overburden Stockpile
Years active	years	2020 -2051	2020 - 2040	2020 - 2051	2020 - 2023
Duration of years active	years	31	20	31	3
Deposition Rate	Mtpa	4.10	6.35	8.76	1.05
Density	t/m3	1.09	1.13	1.30	1.30
Moisture Content at Disposal	% by mass	85%	85%	20%	5%
Maximum seepage water available	m3/pa	15 500	26 000	41 000	3 500
Max Height	m above current ground level	25	25	7	5.6
Hydraulic Conductivity of deposited material	m/s	1.0×10^{-8}	1.0×10^{-8}	2.5×10^{-5}	2.5×10^{-5}
Hydraulic Conductivity of deposited material	m/d	8.6×10^{-4}	8.6×10^{-4}	2.2	2.2
Percent density reduction in consolidated fines	%	40%	40%	40%	40%
Consolidated Fines	m/d	6.0×10^{-9}	6.0×10^{-9}	1.5×10^{-5}	1.5×10^{-5}
Hydraulic Conductivity of consolidated material	m/d	5.2×10^{-4}	5.2×10^{-4}	1.3	1.3
Effective porosity of deposited material	-	0.01	0.01	0.2	0.2
Recharge	m/d	*Transient. See Appendix B*	*Transient. See Appendix B*	*Transient. See Appendix B*	*Transient. See Appendix B*
Potential Evaporation	mm/a	1190	1190	1190	1190
Evaporation Extinction Depth	m	0 -20 m	0 -20 m	1	1
Indicator Element	% source concentration	% source concentration	% source concentration	% source concentration	% source concentration
Source Concentration	%	100	100	100	100
Background Concentration	%	0	0	0	0

5.8.2 Original RSF Results

Three scenarios were modelled according to the proposed EOFS mine plan (0.4% cut off grade) as follows (and described in Section 5.8.1):

- Sc1: No RSF liner required;
- Sc3a: RSF Class C liner (moderate installation); and
- Sc3b: RSF Class C liner (excellent installation).

(Scenario 2 is expected to produce the same results as Scenario 1; thus no modelled runs were required).

These scenarios were modelled from 2020 to 2150, to predict flow and contaminant transport for the following periods:

- Pre-mining: 2020;
- End of Mine: 2051 (31 years active, from 2020); and
- Post-closure: 2070, 2100 and 2150 (20, 50 and 100 years).

<u>Pre-mining results</u>

Pre-mining contaminant plumes (current Tronox operations until 2020) (Figure 5-3 and Figure 5-4) have an average concentration (primarily salinity) in the EOFS area of *c.*20% of source. The Primary Aquifer has higher concentrations than the secondary, due to the increased vertical travel time and greater dilution potential due to the saturated thickness. Higher concentrations *(c.*50% of source) are found near the Groot Goeraap River in the north-east as well as the eastern edge of STF2. The Secondary Aquifer has concentrations of less than 10% throughout most of the EOFS mine footprint, with the exception of slightly higher concentrations *(c.*30%) towards the Groot Goeraap in the north-east.

<u>End of Mine and Post-closure results</u>

The end of mine and post-closure contaminant plumes for the various scenarios (Sc1, Sc3a and Sc3b) from 2051 to 2150 are presented from Figure 5-5 to Figure 5-10 and Table 5-5 to Table 5-6. The modelled results are summarised as follows:

- The plume largely mimics the shape of the seepage area and remains largely within the Mining Rights Area (MRA) during mining and post-closure;
- The contaminant plume migrates from the EOFS mining area in a north-west direction towards the Sout River as well as a north-east towards the Groot Goeraap River;
- The majority *(c.*70%) of the contaminant plume footprint at LoM is under 5% source concentration;
- The maximum concentrations in the Primary Aquifer are *c.*8% higher than the Secondary Aquifer;
- The Secondary Aquifer contaminant plume extends further *(c.*500 m) than the Primary Aquifer; Tailings (shallow areas and STFs) have a maximum % source concentration of *c.*60% and *c.*20% for the Primary and Secondary Aquifer respectively;
- The Overburden Stockpile has a maximum % source concentration of .45% and *c.*20% for the primary and Secondary Aquifer respectively;
- The contaminant plume of the Overburden Stockpile and tailings (backfilled mine void and STFs) is similar for all scenarios (Sc1, Sc3a and Sc 3b);

- Average groundwater concentrations in 2051 in the local area directly underlying the RSF decrease by *c.*7% and *c.*13% for Sc3a and Sc3b respectively, in comparison to Sc1 (Table 5-5), whereas concentrations more than 200m beyond the RSF footprint are very similar across scenarios;
- The greatest subsurface groundwater mounding effect (up to *c.*20 m) in local groundwater levels occur below the RSF;
- The effect of groundwater level mounding is very localised (within *c.*300 m of the source);
- The contaminant plume migrates below the Groot Goeraap River (*c.*10 mbgl) with a maximum concentration of *c.*10% of source;
- The contaminant plume may reach up to 5% of the source concentration within a stretch of *c.*50 m along the southern banks of the Sout River; and
- The contaminant plume dissipates/decreases by an average *c.*30%, 50% and 80% for 2070, 2100 and 2150 for all scenarios respectively; and
- Negligible differences in plume extent are apparent between Sc1, Sc3a and Sc3b. Concentration differences between scenarios are also minor and confined to local to the RSF footprint area.

Table 5-5: Primary Aquifer Concentrations vs. Plume Extent Per Scenario - 2051

Facility	Conc. Max (% of source)			Max distance (m) beyond footprint of facility (where conc. >5%)
	Sc1	Sc3a	Sc3b	
RSF	100	93	87	200
Tailings (shallow areas and STFs)	57	57	57	100
Overburden Stockpile	45	45	45	40

Table 5-6: Secondary Aquifer Concentrations vs. Plume Extent Per Scenario - 2051

Facility	Conc. Max (% of source)			Max distance (m) beyond footprint of facility (where conc. >5%)
	Sc1	Sc3a	Sc3b	
RSF	92	86	80	350
Tailings (shallow areas and STFs)	19	19	19	100
Overburden Stockpile	21	21	21	40

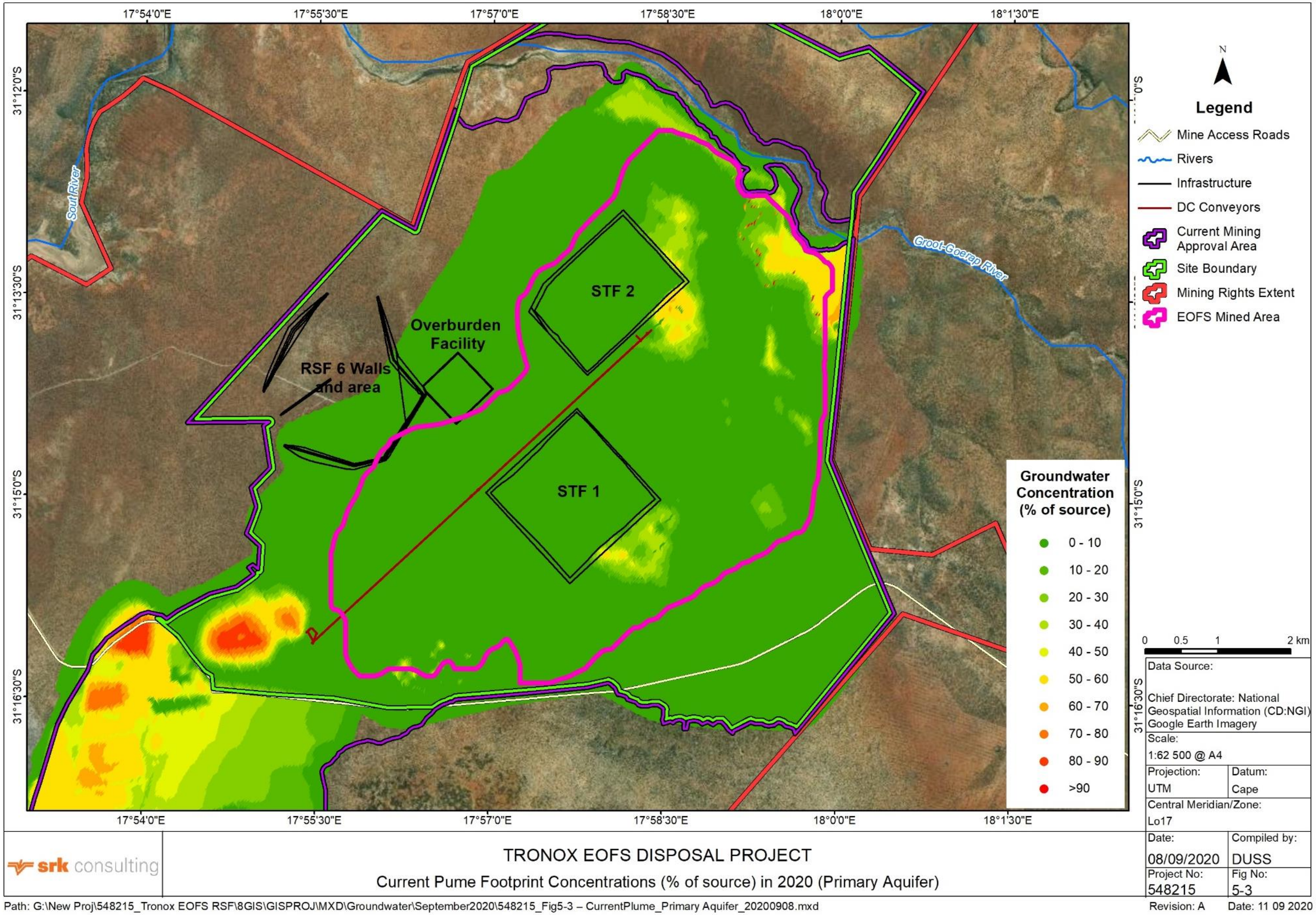

Figure 5-3: Current Plume Footprint Concentrations (% of source) in 2020 (Primary Aquifer)

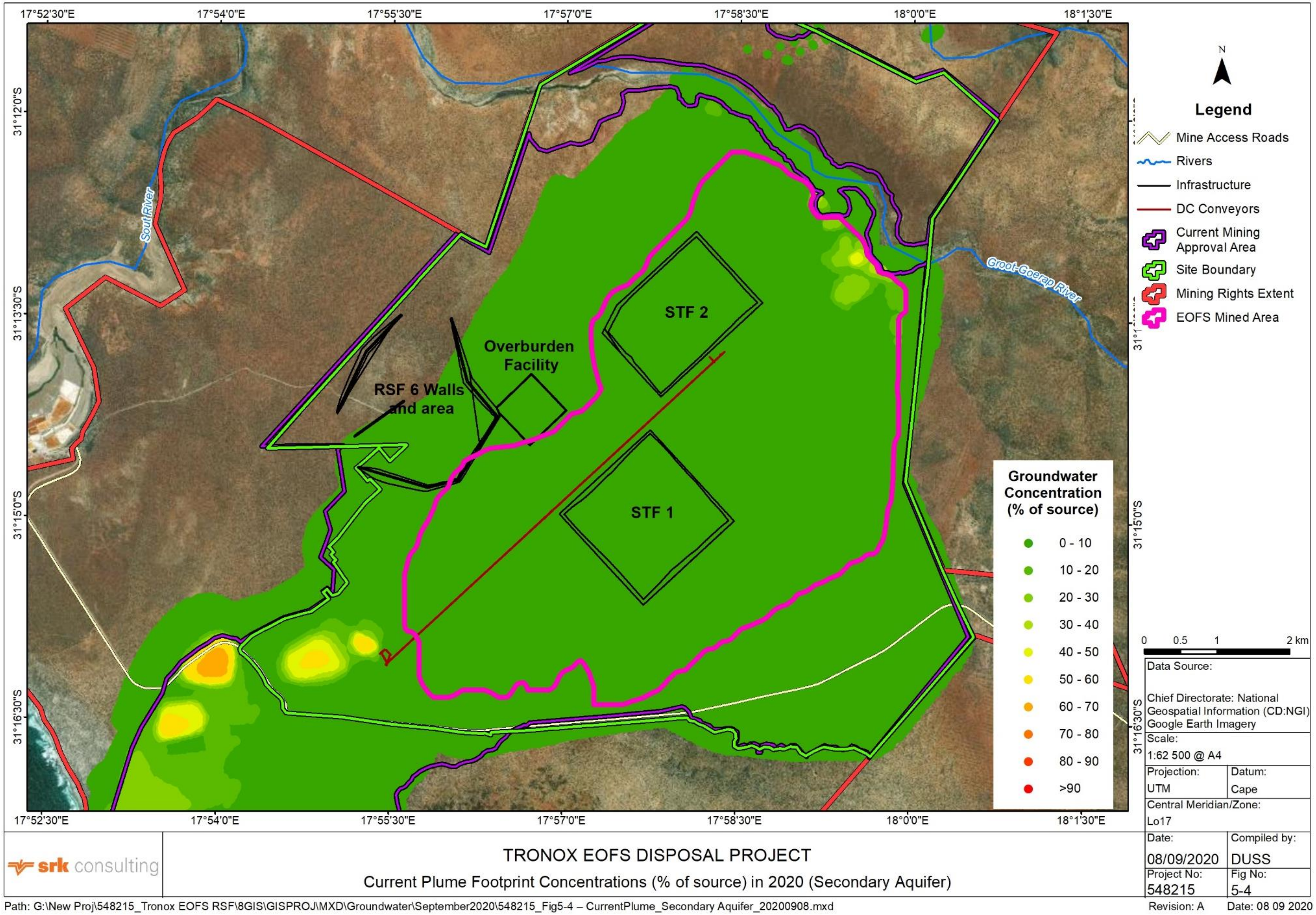

Figure 5-4: Current Plume Footprint Concentrations (% of source) in 2020 (Secondary Aquifer)

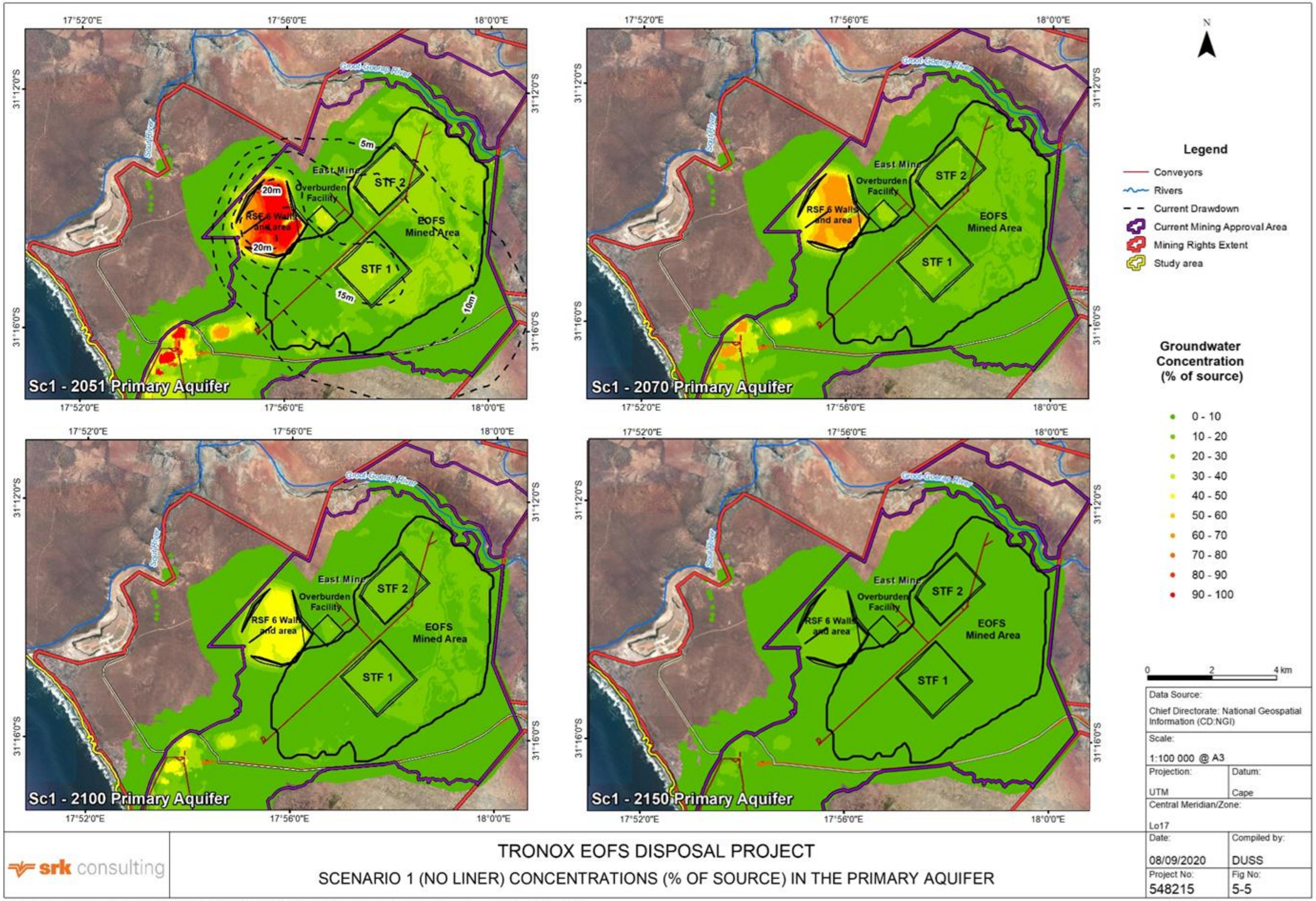

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Figure 5-5: Scenario 1 (No Liner) Concentrations (% of source) in the Primary Aquifer

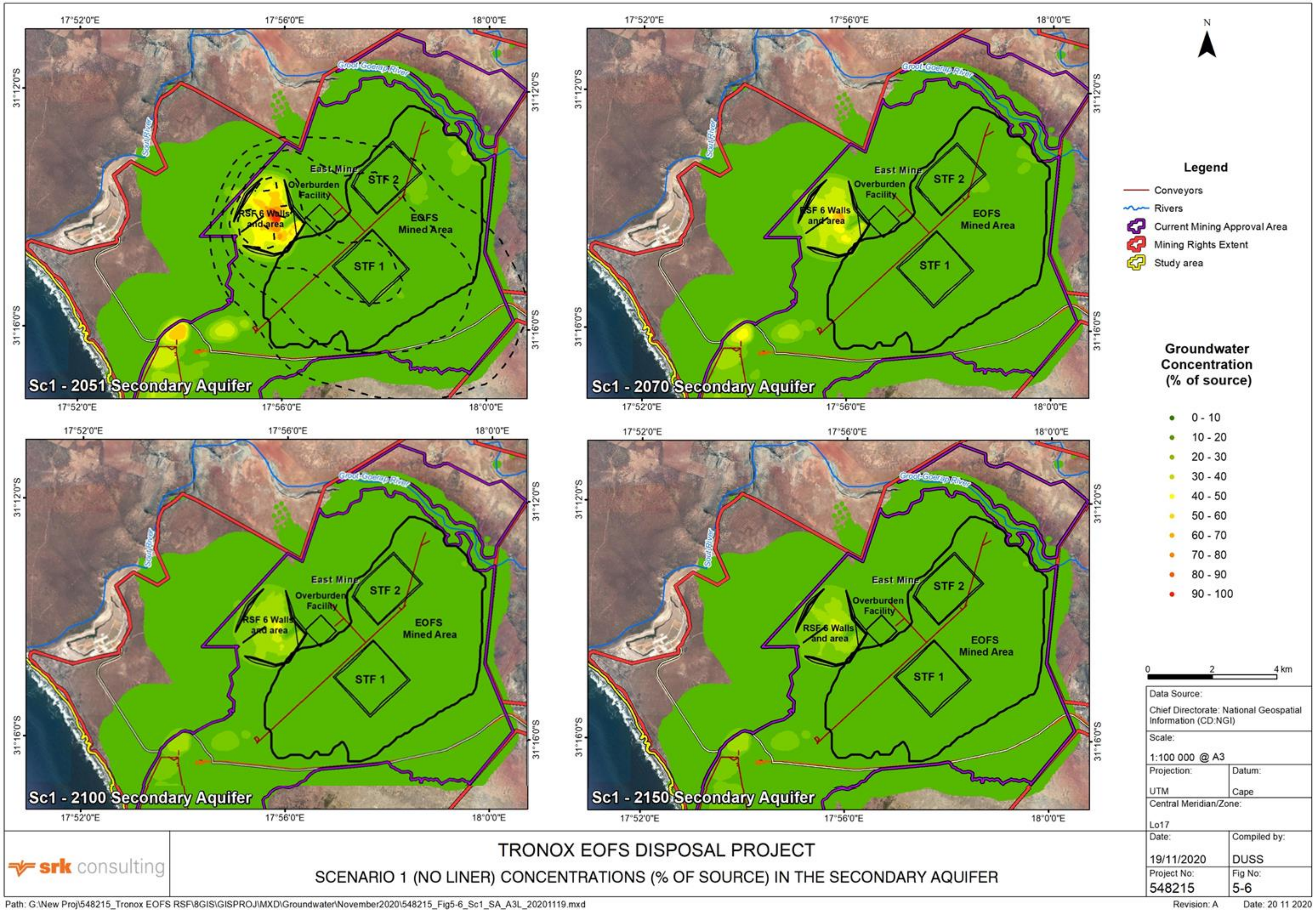

Figure 5-6: Scenario 1 (No Liner) Concentrations (% of source) in the Secondary Aquifer