REPORT

Central Termica de Temane Project - Surface Water

Effluent Discharge Options Assessment

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1.0 INTRODUCTION

Electricidade de Moçambique (EDM) and Temane Energy Consortium (TEC) are proposing the construction and operation of a gas to power plant in Mozambique in the Temane/Mangugumete area, located in the Inhassoro District of Inhambane Province. The project which is known as the Central Termica de Temane (CTT) Project will use natural gas as feedstock and electrical power produced by the facility will be exported to the Mozambican National Power Grid.

The preferred site for CTT Project is located approximately 500 m south of the Sasol Central Processing Facility (CPF). The site is located approximately 40 km northwest of the town of Vilanculos and 30km southwest of the town of Inhassoro. The Govuro River lies approximately 8 km east of the proposed CTT site (Figure 1). The estimated footprint of the CTT power plant is approximately 20 ha.

The CTT plant with generation capacity of up to 450MW will include a facility with a power generation block, an outside battery limit and the plant infrastructure. Combined Cycle Gas turbines (CCGT) is the proposed technology to be adopted at the CTT plant to generate power using the natural gas.

Water supply to the CCT, will include raw water from the local aquifer system that will be treated accordingly for supply of potable water, utility water, demineralised water, filtered water and water for fire-fighting.

The liquid effluents to be produced by the CTT plant includes ultrafiltration and RO reject, HRSG boiler blow down, ion exchange regenerate, sewage effluent, oily water from rainwater, fire water or wash down at potentially oil contaminated areas and spent oil.

Globeleq, appointed Golder Associates (Golder) to assess identified options to manage the effluent discharges from the CTT plant. The objective of the assessment is to evaluate the impact of the identified options and cost the options to allow for a high-level cost comparison.

This report presents the results of the assessment of the suite of effluent discharge options.

2.0 EFFLUENT DISCHARGES

With the use of the CCTG technology, the heat recovery steam generators will use hot make up demineralised water to generate steam that will be converted to electrical power via the steam turbine and generator. The water quality is to be controlled by the injection of suitable chemicals and by blowing down a small quantity of boiler water. The process will result in the need to discharge two effluent streams, *viz.*

- The reverse osmosis (RO) brine (from demineralisation process); and
- The HRSG blowdown of boiler water.
- The expected volumes of the effluent streams generated are shown in **Error! Reference source not found.**

Table 1: Volumes of HRSG and RO brine to be generated

Discharge	RO Brine volume (m^3/h)	HRSG blowdown volume (m^3/h)	Total discharge m^3/hour (continuous)	Temperature of combined
Mean water flow rate	3.05	4.04	**7.09**	42°C
Maximum water flow rate	6.2	3.9	**10.1**	

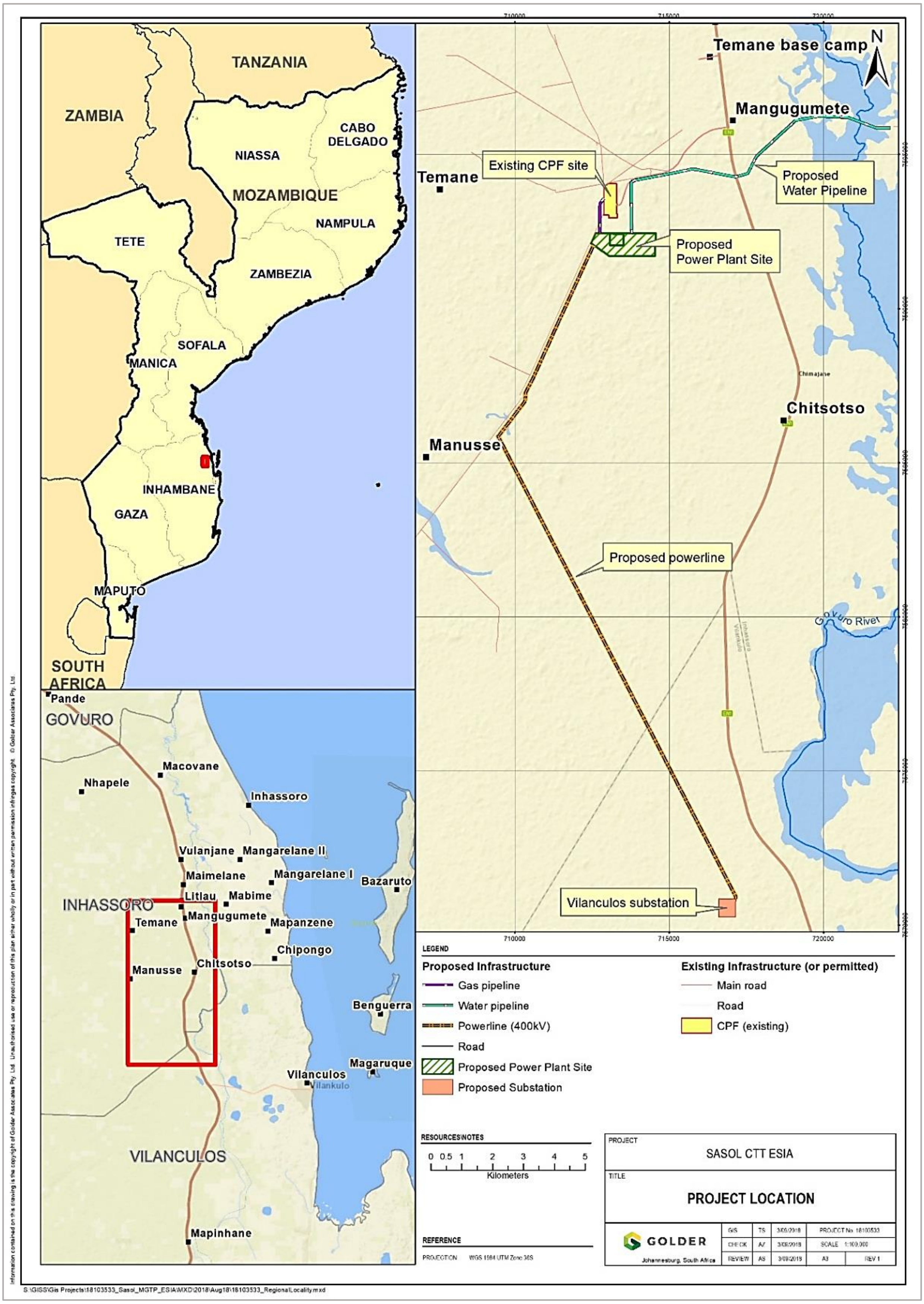

Figure 1: CTT Project location

The expected quality (approximate concentrations) of the effluent streams to be generated are shown in Table 2. The analysis describes the effluent stream, which permitted the identification of the constituents of concern *i.e.* parameters that do not meet regulatory specifications and have the potential to negatively impact the receiving environment.

Table 2: Expected chemical quality of the effluent streams to be generated

Water Quality parameter	RO Brine	HRSG Blowdown
pH (pH units)	6.8	9.5 - 9.8
Temperature		55°C
Ammonia (mg/l)	<0.55	5
Sodium (mg/l)	845	0.02
Chloride (mg/l)	1 282	0.02
Sulphate (mg/l)	242	0.02
Silica (mg/l)	-	1
Iron (mg/l)	0.124	0.01
Aluminium (mg/l)	-	0.01
Calcium (mg/l)	518	
Total Dissolved Salts (mg/l)	5 590	18 to 30
Dissolved Zinc (mg/l)	0.84	
Dissolved Manganese (mg/l)	0.05	
Magnesium (mg/l)	307	
Dissolved Chromium (mg/l)	0.056	
Dissolved Boron (mg/l)	1.475	
Electrical Conductivity (mS/m)	917	3 - 5
Potassium (mg/l)	30.3	
Nitrate (mg/l)	5.95	
Nitrite (mg/l)	0.05	

Based on the quality of the effluent stream, the major and important constituents influencing the irrigation of the effluent stream (as option 1) and the aquifer injection (as option 2) is the salt concentration, which can affect ground water quality. The elevated temperature of the effluent is also important consideration in terms of the receiving environment.

3.0 EFFLUENT DISPOSAL OPTIONS

The effluent disposal options were devised based on discussions with Globeleq at a meeting held on Thursday, 9 May 2019 and follow-up e-mail correspondence of 15 May 2019. The effluent disposal options identified, are as follows:

- **Option 1**: Aquifer Injection System into the karst aquifer considering the injection of both the HRSG and demineralisation effluents into aquifer after mixing (possible treatment before injecting).
- **Option 2**: Surface discharge by irrigation:
  - Irrigation of the mixed HRSG and demineralisation effluents;
  - Dilution with well water prior to irrigation.
- **Option 3**: Discharge to Evaporation ponds:
  - Standard option;
  - Enhanced option - aided evaporation.
- **Option 4**: Evaporator Crystallizer

This report presents the impact assessment results of Options 1 and 2 in terms of the discharge criteria as listed in Table 3, and includes the high-level costing for the options 1 to 4.

Table 3: Effluent disposal criteria for options 1 and 2

	RO Brine volume (m^3/h)	HRSG blowdown volume (m^3/h)	Quenching water (m^3/h)	Total discharge m^3/hour (continuous)	Temperature
Option 1: **mean water flow rate** Injection to aquifer	3.05	4.04		**7.09**	At 42°C
Option 2: **mean water flow rate** Surface irrigation (mixing with quenching water to reduce temperature)	3.05	4.04	25.3	**32.4**	At 30°C

4.0 EFFLUENT DISPOSAL REQUIREMENTS

In Mozambique, environmental standards are regulated by the Ministry of Health, through the National Department of Environmental Health. Legislation applicable to the effluent discharges have been published however these are applicable to discharge to a receiving water body and thus are not relevant in terms of Option 1 or 2.

The requirements applicable to the irrigation of water, include Mozambican Regulation on Environmental Quality Standards and Effluent Emission - Decree No. 18/2004 of 2 June – Article 12 – Water Quality Parameters for Use of Water as listed in Table 4. Additional recommended intervals and water classification as per Appendix VI of Decree No. 18/2004 - Manual for the Classification and Interpretation of Laboratory Analyses of Soil and Water also apply for effluent to be used for irrigation (APPENDIX A).

Table 4: Water Quality Requirements for Irrigation

Component	Units	Standards
Total Dissolved Solids	mg/l	<500
Bacteria (total)	cfu/100ml	<= 100000

As the potential effect of the effluent disposal of Options 1 and 2 would be on groundwater quality, the impact to receiving 'downstream users' would be a risk to domestic use (local villages), primarily drinking water (*i.e*. use of the groundwater as a raw water source) over the short and long term beyond life of operation. The effluent discharge quality was thus compared to the South African Domestic Use water quality guidelines (DWAF, 1996) to identify the constituents of potential risk to human health (see Table 5) (Note: the acceptable level for human health indicated guideline may have some aesthetic effect). Potable water quality standards for Mozambique are included in Table 5 for completeness however, these are not applicable, as 'potable' would imply a level of treatment to achieve compliance, which is not of relevance in terms of the impact assessment.

The effluent disposal will include mixing of the effluents prior to injection or irrigation. The effluent streams will be mixed at a ratio of 0.75:1 (RO Brine to HRSG blowdown), which allows for dilution of the RO brine effluent concentration. Table 5 includes the qualities of the resulting effluents on mixing for the aquifer injection and irrigation options.

From the comparison, it is evident that the concentrations of the major salts are of potential risk to downstream users in the villages who are directly reliant on the groundwater for domestic use. High salinity concentration is primarily associated with diarrhoea, nausea and exacerbation of certain disease conditions (e.g. hypertension, cardiovascular disease), as risks to human health and bitter, salty taste, scaling, corrosion and inhibition of soap lathering in terms of aesthetic effects. The presence of the elevated ammonia in the effluent (approximately 3 mg/l on mixing and further expected dilution within the aquifer) does not pose a human health risk. Objectionable taste and odours are possible at an ammonia concentration of 2mg/l.

Table 5: Quality of the effluent streams as compared to domestic use water quality guidelines and potable water standards

Water Quality parameter	RO Brine	HRSG Blowdown	Combined RO and HRSG Blowdown (aquifer injection)	Combined RO and HRSG Blowdown and quenching water (irrigation)	Domestic Use Water Quality Guideline (SAWQGs, 1996) (Acceptable – safe level)	Potable Water Quality Standard (Mozambique, Ministerial Diploma No 180/2004)
pH (pH units)	6.8	9.5 - 9.8			6.0 – 9.0	6.5 – 8.5
Temperature		55°C	42°C	30°C		
Ammonia (mg/l)	<0.55	5	3.09	0.75	2.0	1.5
Sodium (mg/l)	845	0.02	363.5	211.5	200	200
Chloride (mg/l)	1 282	0.02	551.5	320.6	200	
Sulphate (mg/l)	242	0.02	104.1	60.3	200	250
Silica (mg/l)	-	1				
Iron (mg/l)	0.124	0.01	0.06	0.03	1.0	
Aluminium (mg/l)	-	0.01	0.01	0.002	0.15	
Calcium (mg/l)	518		222.8	130	150	50
Total Dissolved Salts (mg/l)	5 590	18 to 30	2421.8	1388.7	1 000	1 000
Dissolved Zinc (mg/l)	0.84		0.36	0.21	10	
Dissolved Manganese (mg/l)	0.05		0.02	0.01	0.1	0.1
Magnesium (mg/l)	307		132.1	76.8	70	50

Water Quality parameter	RO Brine	HRSG Blowdown	Combined RO and HRSG Blowdown (aquifer injection)	Combined RO and HRSG Blowdown and quenching water (irrigation)	Domestic Use Water Quality Guideline (SAWQGs, 1996) (Acceptable – safe level)	Potable Water Quality Standard (Mozambique, Ministerial Diploma No 180/2004)
Dissolved Chromium (mg/l)	0.056		0.02	0.01	0.050	
Dissolved Boron (mg/l)	1.475		0.63	0.37		2.4
Electrical Conductivity (mS/m)	917	3 - 5			150	5 - 200
Potassium (mg/l)	30.3		13.03	7.58	50	
Nitrate (mg/l)	5.95				6.0	
Nitrite (mg/l)	0.05					

5.0 PHYSICAL DESCRIPTION OF AQUIFER REGIME

The topography of the proposed CTT plant site is uniformly flat to gently undulating and low-lying. To the east of the proposed site, the Govuro River channel is situated at ±13 m above mean sea level (mamsl). The Govuro River flows parallel to the coast from south to north. Mean annual rainfall is between 800 – 1 000 mm, decreasing from the coastline in a westerly direction.

At the proposed Globeleq CTT plant site, the hydrogeological regime consists of two units, a shallower perched aquifer associated with the overlying red soil and the shallow weathered, leached and fractured limestone aquifer that extends to a depth of 13 to 18 mbgl (Rison, 2019). The base of the perched aquifer is defined by an impermeable clay layer that varies in thickness. This aquifer is secondary, unconfined, perched and generally only contains water after heavy rainfall events. The permeability was estimated by subjecting two shallow boreholes to falling head tests and values of 1.5 x 10^{-3} to 2.3 x 10^{-3} m/s were obtained (Palmer, 2003).

The deeper aquifer is the Jofane limestone (karst) aquifer, and this exists below the clay layer and is described (Rison, 2019) as extending to a depth of approximately 100 mbgl. The degree of weathering decreases with depth to about 22 m. Below 22 m a leached and fractured limestone is present. The fracturing extends to about 35 m. Below 35 m this limestone is described as leached, and in places as honeycombed and/or cavernous.

The depth to groundwater level is measured to be 14.85 mbgl in the water supply well. In addition, reference is also made to a hydrocensus of groundwater points in the area that was done by Rison during a previous study of the area. A total of 47 water levels were used which showed that regionally the depth to groundwater level in the limestone aquifer generally range between 10 and 20 to 25 mbgl.

An aquifer test that was done on the water supply well (Rison, 2019) showed an aquifer transmissivity of approximately 175 m^2/day for the limestone aquifer. Previous aquifer tests that have been performed on this aquifer estimates the transmissivity to range between 540 m^2/day and 3 700 m^2/day.

The aquifer is clearly heterogeneous which explains why there is only a 75% correlation between topography and groundwater level elevation. Rison (2019) estimates that this aquifer is recharged at a conservative rate of 5% of the MAP.

Figure 2 below is west to east schematic cross-section showing the general conceptual understanding of the hydrogeology of the area being considered (Rison, 2019).

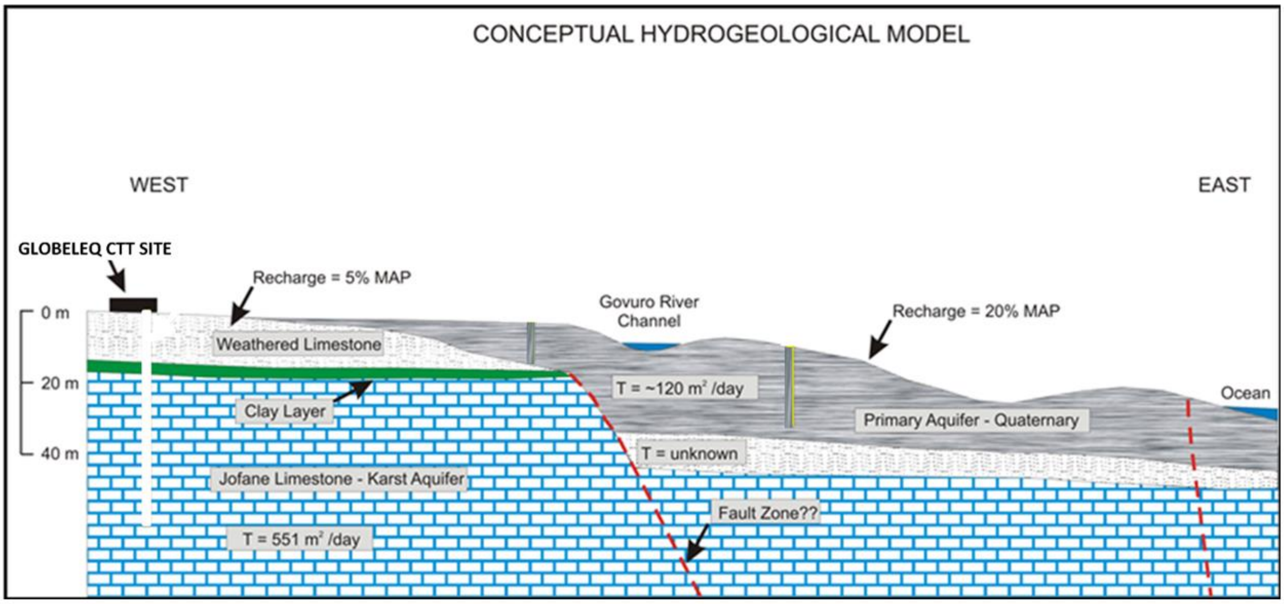

Figure 2: General conceptual understanding of the hydrogeological regime (taken from Rison 2019, modified after van Bart, 2009)

6.0 METHODOLOGY

The salt concentration of the effluents pose a risk through the disposal via injection and irrigation, due to the potential impact on soil and ground water quality. Based on the evaluation of the water quality constituents of concern, chloride was selected as the salinity indicator parameter to assess the groundwater impact of the contaminant plume with respect to scenarios of option 1 and 2, due to it being the highest concentration cation present in the effluent. In addition, as the effluent is a thermal discharge from a power generation plant, it was also necessary to determine the risk of the elevated temperature on the receiving water environment, as this could potentially change the temperature regime of the water column (potentially an indirect effect on the ecosystem).

Numeric groundwater modelling of chloride as the representative salinity parameter and of temperature was undertaken.

A single injection well was used to demonstrate the likely impact of injecting the effluent at an arbitrary position to the south of the proposed new CTT plant site, while a 50-hectare irrigation area was chosen to the east of the proposed CTT plant site.

The depth of the injection in the well was chosen at a depth of 32 m, which coincides with the base of the upper layer of the deeper confined/semi-confined karst aquifer underlying the CTT plant site.

The irrigation field was applied to the top slice of the numerical model and as assumed to enter the shallow aquifer immediately, without delay of unsaturated vertical flow movement and retardation effects such as cation exchange capacity, which would cause further plume migration delays. A conservative approach is thus illustrated by these groundwater flow simulation outputs.

6.1 Calibration

In order to check the suitability of the existing model to simulate the results of proposed effluent discharge options mentioned above the numerical model was calibrated in the steady state against the known groundwater levels in the region measured during a regional hydrocensus undertaken in 2014. Approximately 80 water level monitoring points were used in the initial calibration attempts, however on further investigation it was concluded that significant numbers of these measured water levels may not reflect static groundwater levels and that a complete inventory of abstraction of groundwater for both the village and other purposes is not reflected in the hydrocensus data. Another observation was that many of the monitoring boreholes in the elevated dune zone, away from the project site did not calibrate well.

After exclusion of these groundwater levels and confirming that several of the observed groundwater levels were very close to or in actual abstraction wells and therefore are not likely to represent static water levels (*i.e.* Temane Abstraction Wells) approximately 50 remaining water level observations were included in the calibration process. A root mean square error of 5.63% was obtained, with a NRMSE of 13.4%. The calibration of the groundwater levels was further calibrated against the abstraction rate from two known abstraction wells (W5A and T9) and flow ranges ascribed to the Govuro River (Figure 3).

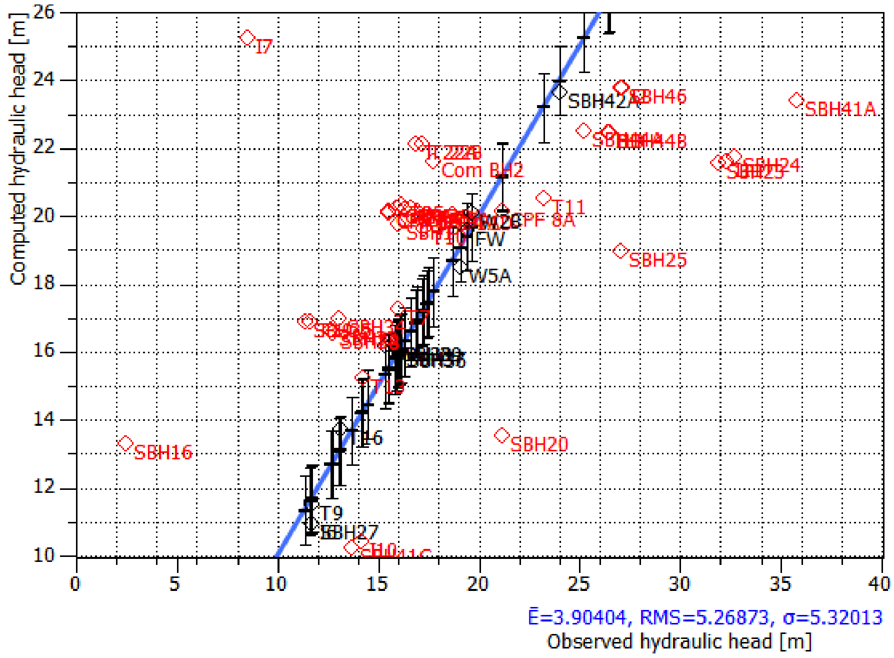

Figure 3: Calibration Scatter plot

The hydraulic conductivity (K) of the shallow and deep aquifers were substantially reduced from the previous model, as were the direct rainfall recharge values assigned to the upper (Layer1) aquifer (50mm/annum – 25 mm/annum). Although a wide range of K values are to be expected in a karst environment it is believed that conceptually the lower regional K values obtained from the latest calibration, taking into consideration stated aquifer thicknesses are more in line with calculated transmissivity values (T) obtained from various tests conducted to date (Table 6).

Table 6: Calibration adjustments of model K values

Model Layer	Intial Kxyz value range (m/day)	Final Kxyz value range (m/day)
Layer 1	65-97	15-20
Layer 2	0.01-97	0.01-10
Layer 3	56-97	3-20
Layer 4	0.01-56	0.01-20

Model Layer	Intial Kxyz value range (m/day)	Final Kxyz value range (m/day)
Layer 5	56-80	0.5-20

7.0 RESULTS OF ASSESSMENT

Figure 4, shows the layout of the proposed CTT plant site as well as the location of the existing Sasol plant to the north. The arbitrary injection well and a 50-hectare irrigation field location in terms of Option 1 and 2 as indicated Figure 4 are used for the simulation of the impacts in the numerical modelling.

7.1 Option 1: Aquifer Well Injection

7.1.1 Mass

Based on the information supplied the injection of the effluent was simulated at a rate of 200 m^3/day with a constant chloride concentration of 640 mg/L at a temperature of 42° Celsius (°C). The groundwater quality monitoring from various monitoring boreholes in the area suggest that the background chloride level is in the order of 100-150 mg/L.

Figure 5 below illustrates the development, in the deeper aquifer, of a contamination plume, represented by the Cl concentration. Snapshots of the extent of the contamination plume (i.e. Cl concentrations above a background value of 100mg/L) at various times (*i.e*. 1 year, 5 years, 10 years and 25 years) after the effluent injections commences are shown. Figure 6, shows the same Cl concentration plume development in cross section along line A-B (Figure 4).

It is assumed that injection of the effluent will continue for a period of 25 years. The numerical groundwater model was also used to simulate the anticipated dissipation of the contaminant plume following this period of effluent injection for a further period of 50 years. This illustrated by snapshots in time of the Cl concentration in Figure 7. This figure shows how, over time, the contamination plume migrates in a north-easterly direction and diminishes in concentration by dilution. Figure 8 shows the migration of the plume post-injection along line A-B (Figure 4).

The concentration of chloride, as it migrates and dilutes, does not present a risk to human health. An upper limit range of 600 mg/l can be tolerated for drinking water, having a distinctly salty taste is imparted to water at this concentration range.

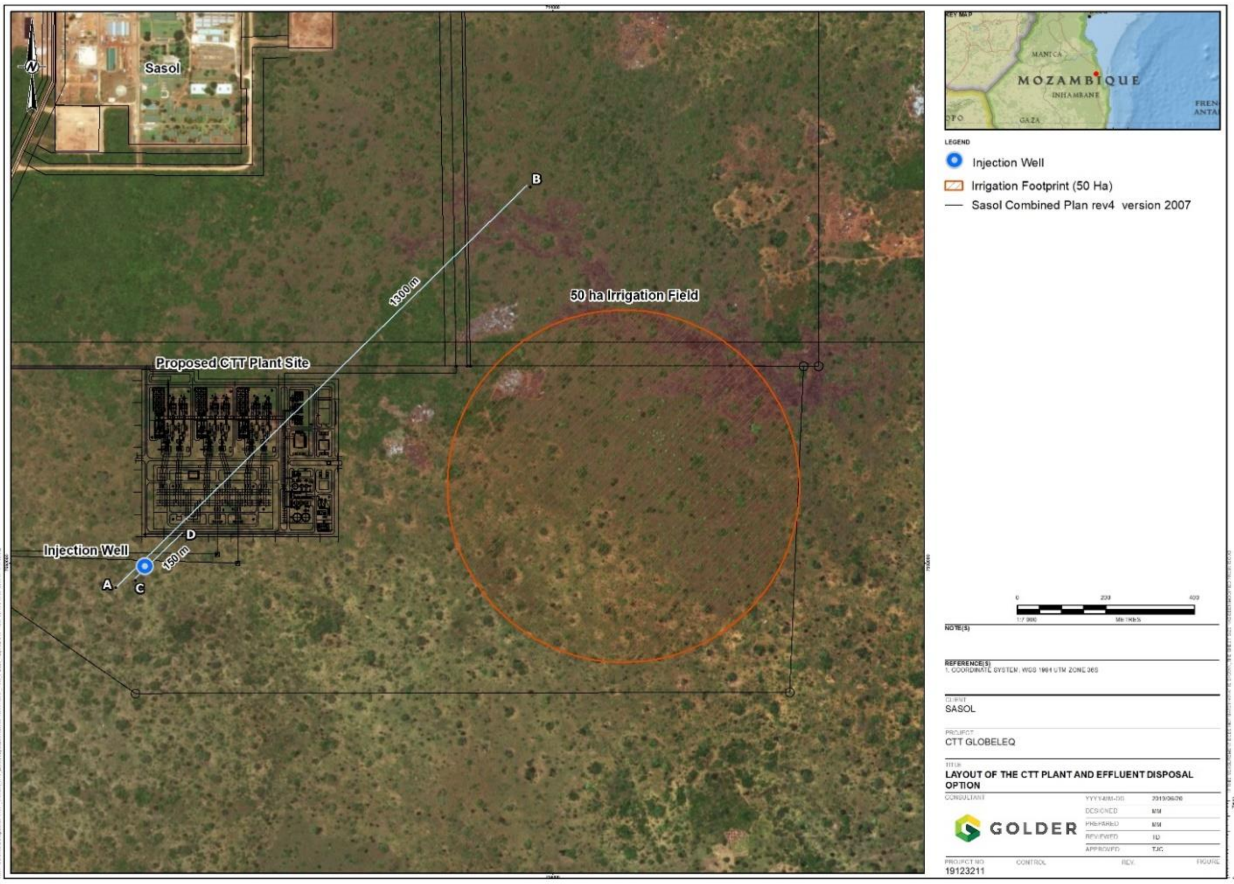

Figure 4: Map showing arbitrarily placed effluent injection well to the south and 50 ha irrigation field to the east of the proposed CTT plant for simulation purposes

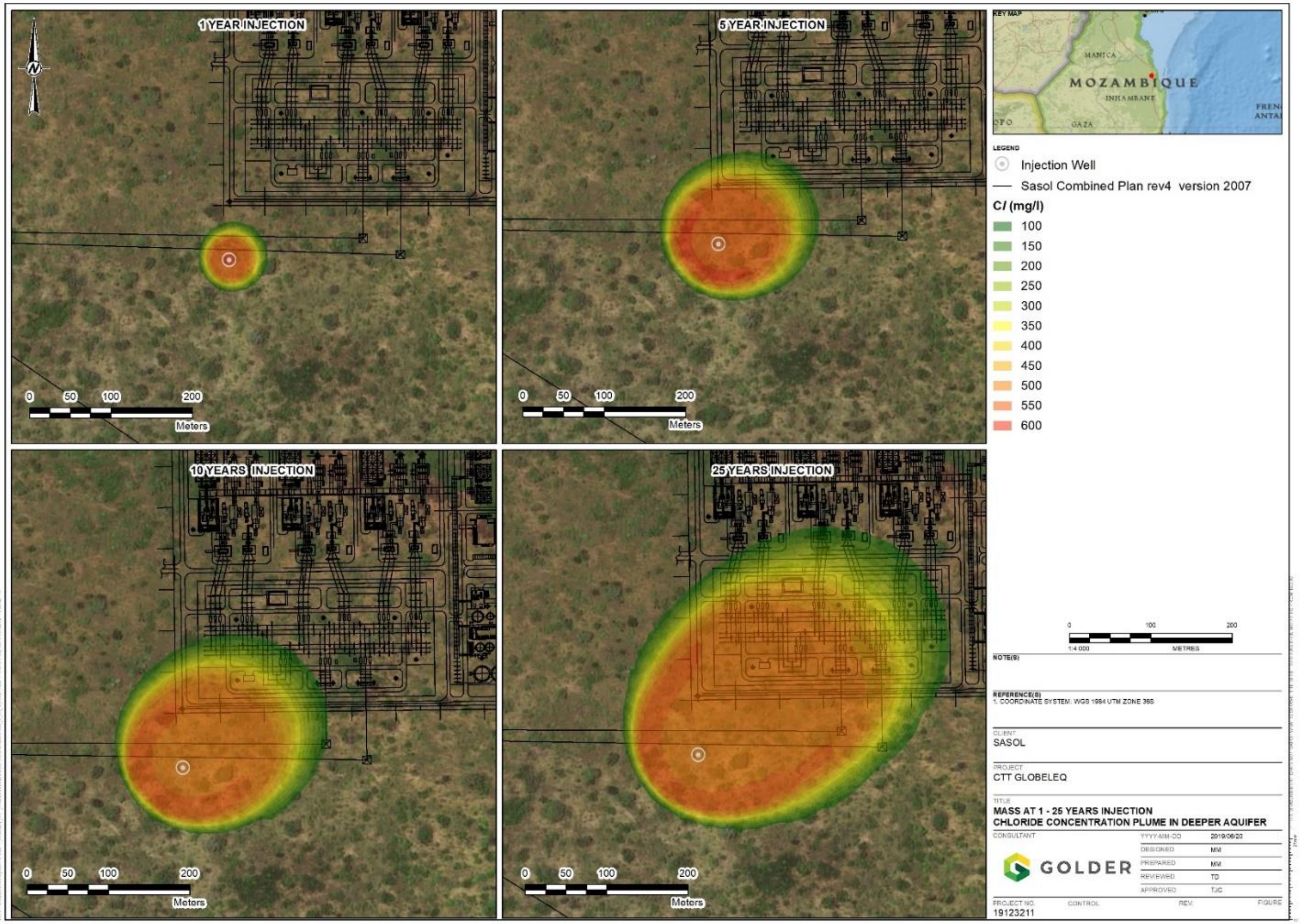

Figure 5: Snapshots in time of chloride concentration because of aquifer injection of the CTT plant effluent

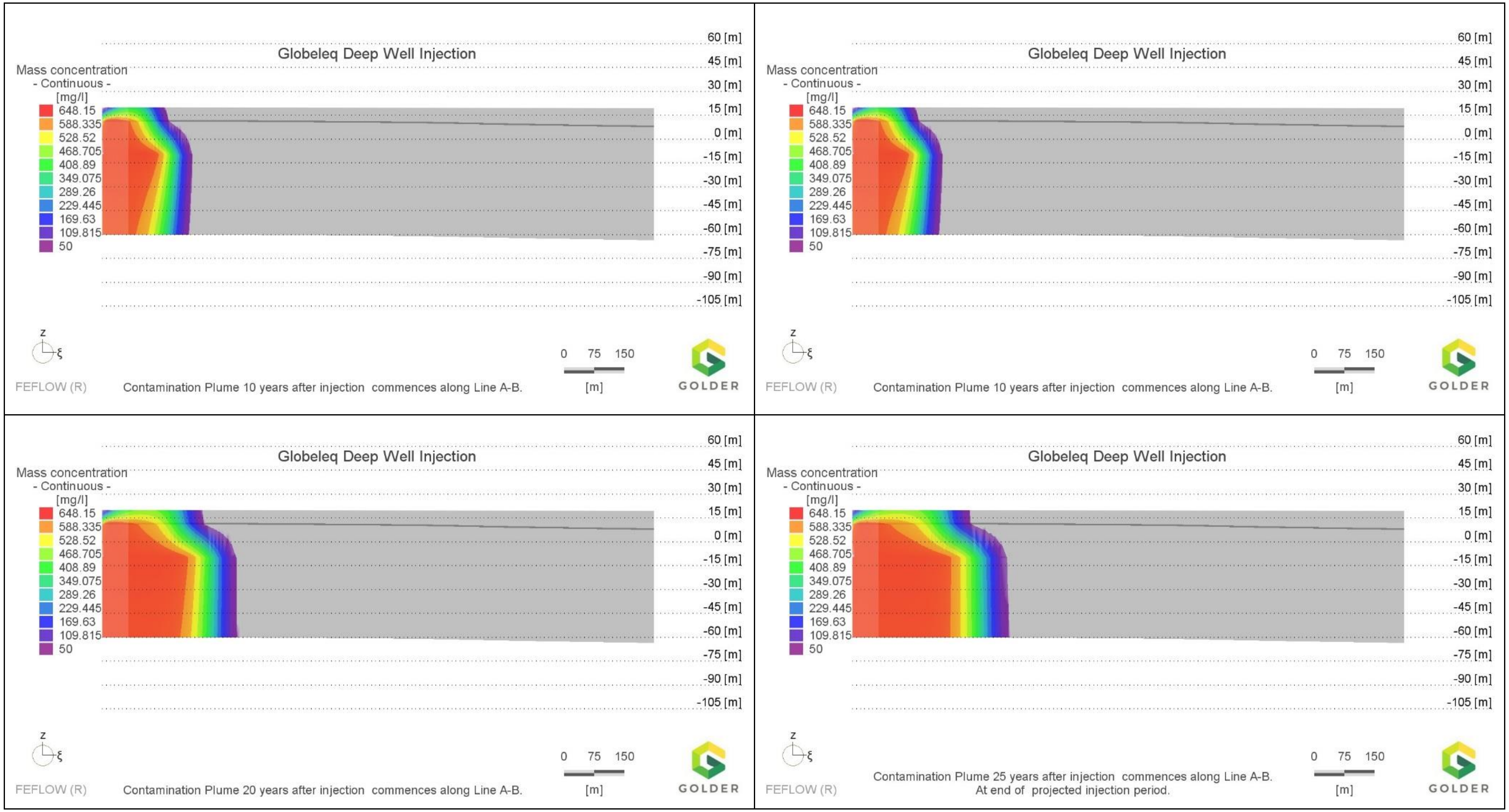

Figure 6: Snapshots of the simulated contamination plume and likely Cl concentrations from injection well in a north-easterly direction along Line A-B (see Figure 4) over 25 years of the CTT plant effluent injection into the deeper karst aquifer

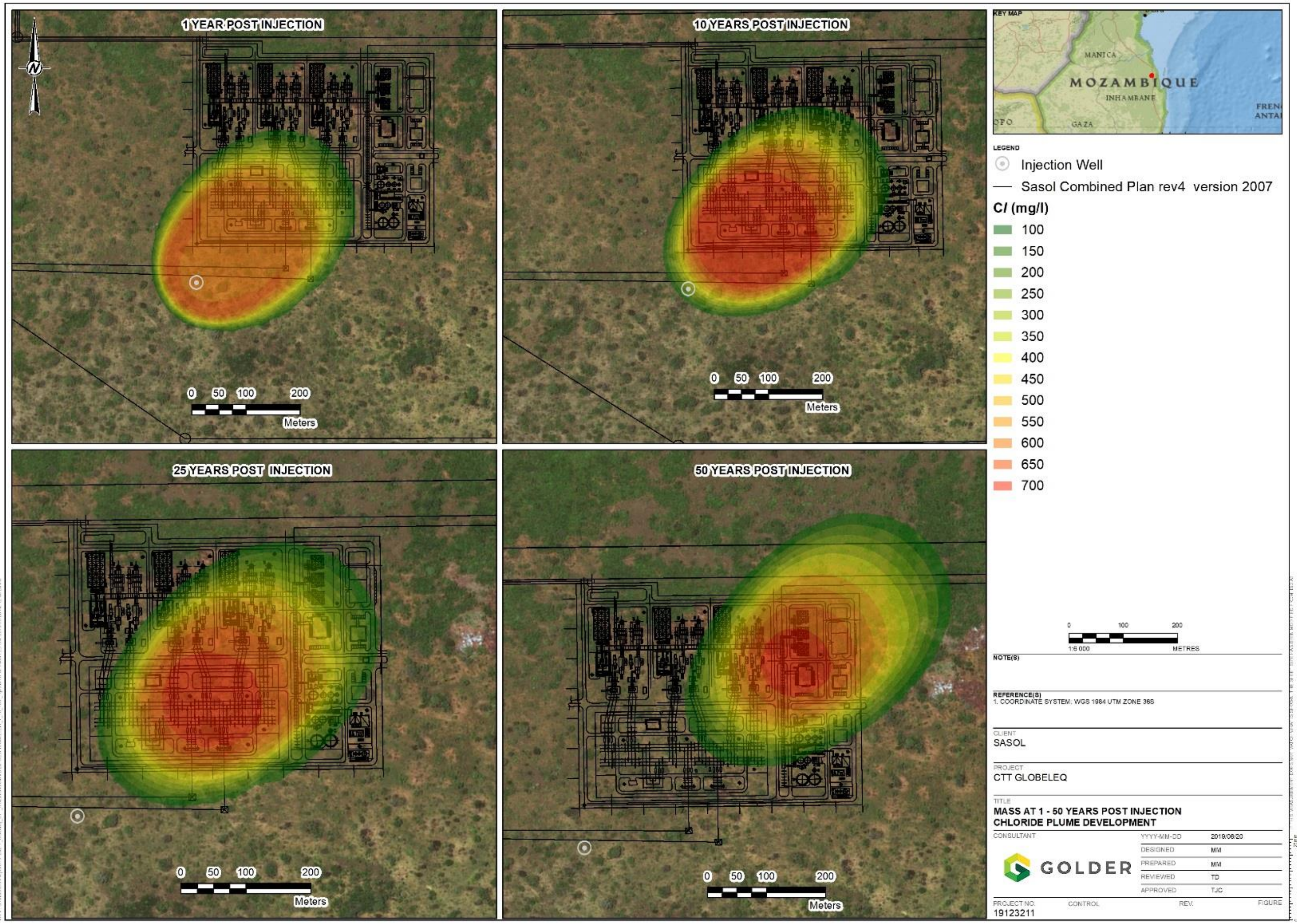

Figure 7: Snapshots in time of Cl concentration of the migration of the plume 50 years post-injection of the CTT plant effluent

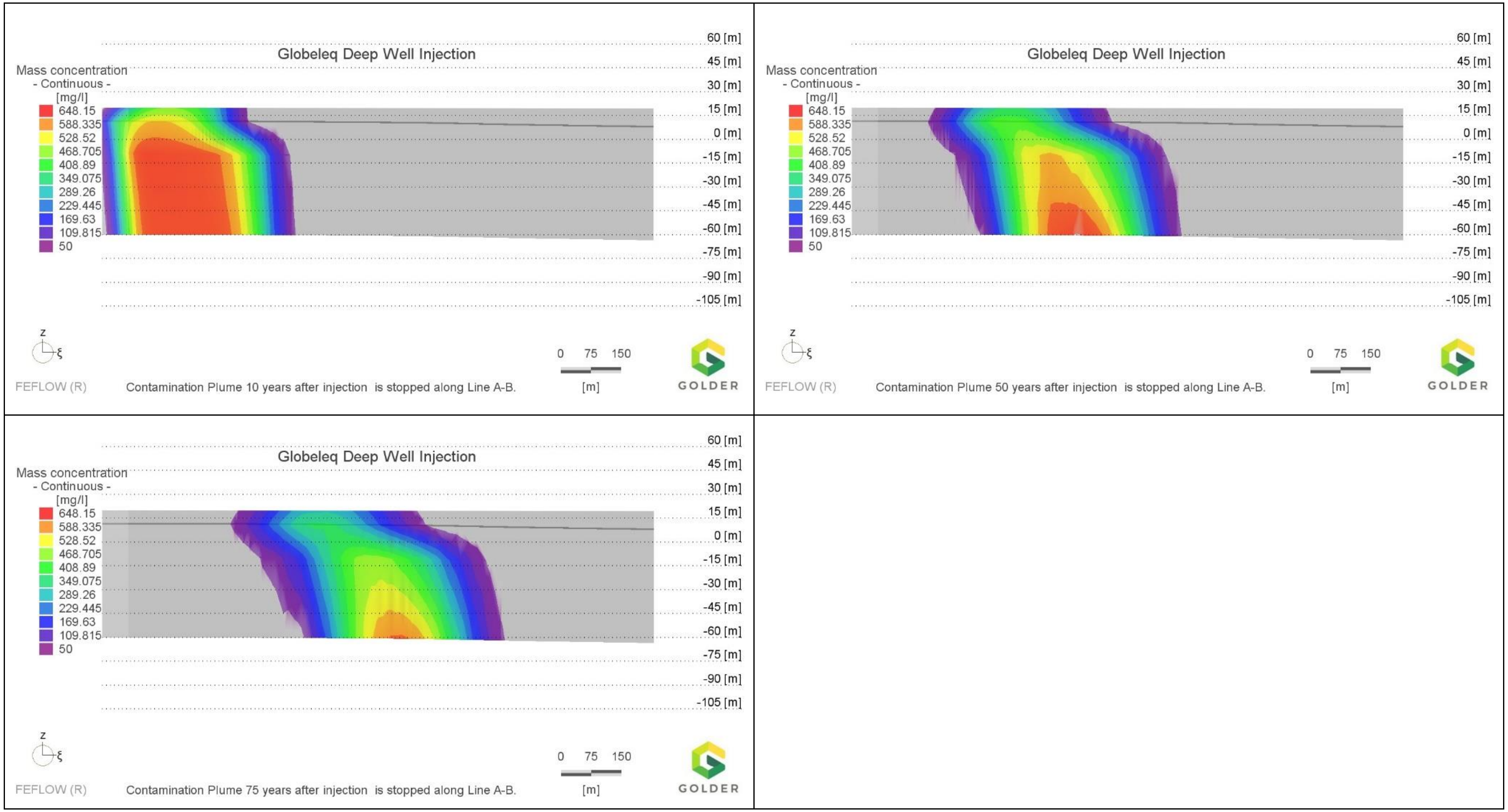

Figure 8: Snapshots of the simulated contamination plume and likely Cl concentration for a period of up to 75 years after injection of the effluent into deeper karst aquifer is stopped

Additional calculation cases were considered for the aquifer well injection scenario. In order to demonstrate the effect of a 20 % higher injected chloride mass concentration (750mg/L) and a 20% higher injected volume (240m^3/hour), two additional scenarios were run to illustrate the impact of such (Figure 9, Figure 10).

Graphs of other relevant salinity ions, sulphate and calcium, in addition to chloride, showing the increased predicted concentrations in the shallow and deep aquifers at distance of 100, 200 and 300m NE of the injection well along line AB (Figure 4) are shown in Figure 11.

The presence of the increased concentrations of the chloride, calcium and sulphate in the shallow aquifer (between 5 years injection and 50 years post injection) do not pose any health risk to receiving water users. The calcium mass concentration, however does pose aesthetic effect risk for users, causing scaling problems and severely impairing lathering of soap. The migration distance of the plume is within the plant site and thus limited impact on the users is expected.

7.1.2 Temperature

A similar approach was used to illustrate the impact of the injection of the effluent at a raised temperature of 42°C, assuming the background temperature of the deeper aquifer to be at 25 °C. The simulation of changes in the temperature around the effluent injection well are illustrated in Figure 12. Snapshots in time are presented at 1 year, 2 years, 10 years and 25 years after injection commences. Similarly, Figure 13 shows the same changes in temperature around the injection well along line C-D (Figure 4) in cross-section. Post-injection temperature changes are reflected in Figure 14 and Figure 15 (Cross Section). Unlike with the chloride concentration which migrates and dilutes at slow rate, the temperature dissipates relatively fast. The maintained elevation of the temperature is a function of the heat conductance and transfer of heat to rock from the water during injection and vice versa thereafter.

A 20 % higher temperature (50°C), was also simulated as an additional scenario and is illustrated as various snapshots in time in Figure 16.

The impact of the discharge of the heated effluent may, however, manifest in other ways not contemplated here which may be more lasting or permanent. This may manifest as increased mineral growth/dissolution, bacterial growth impacts and unqualified/unquantified impacts on stygofauno of which no records are known to exist at the location.

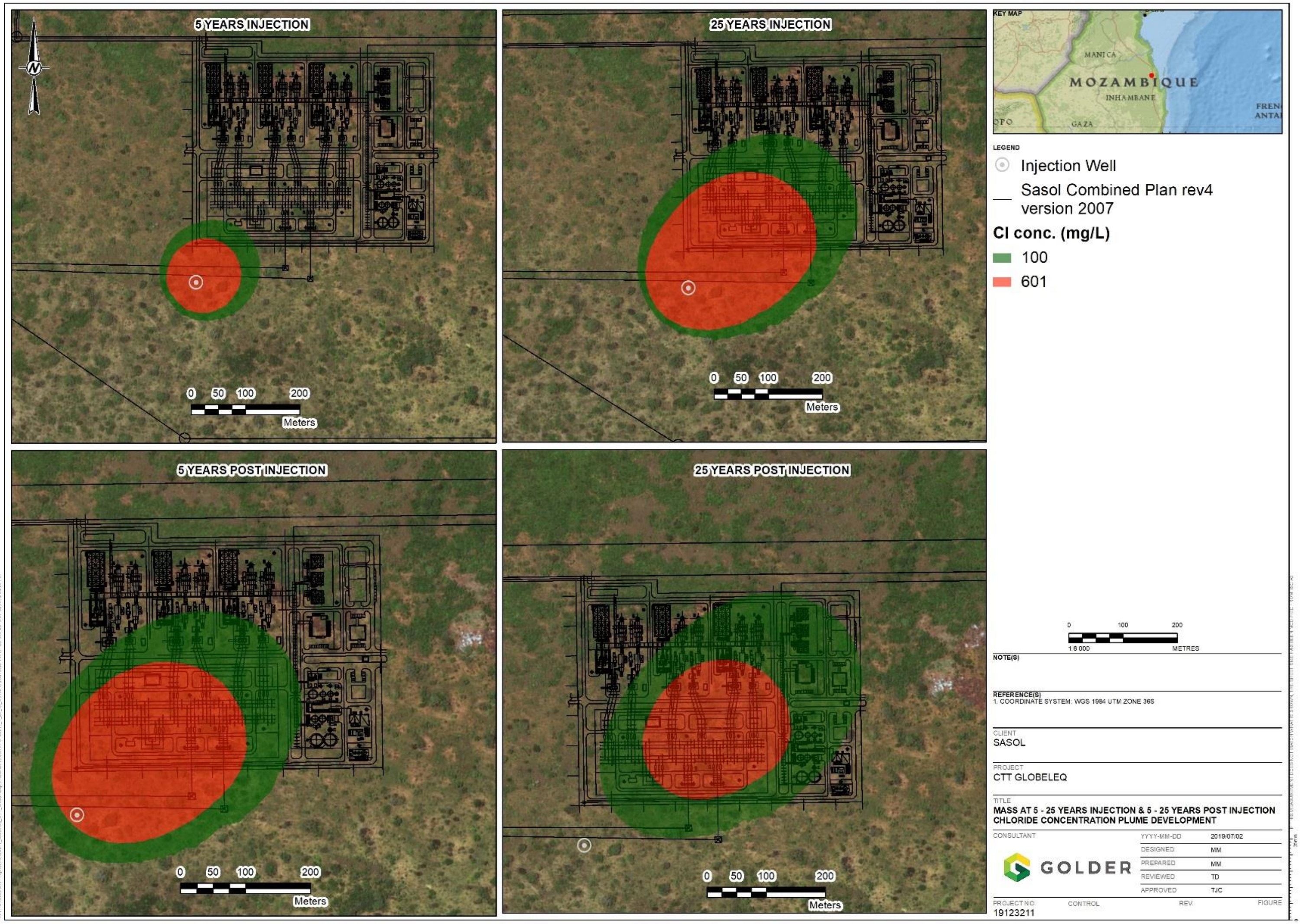

Figure 9: Simulated chloride plume at snapshots in time (5,25 years injection and 5,25 years post-injection) assuming a 20% higher chloride (750 mg/L) concentration in the injection well

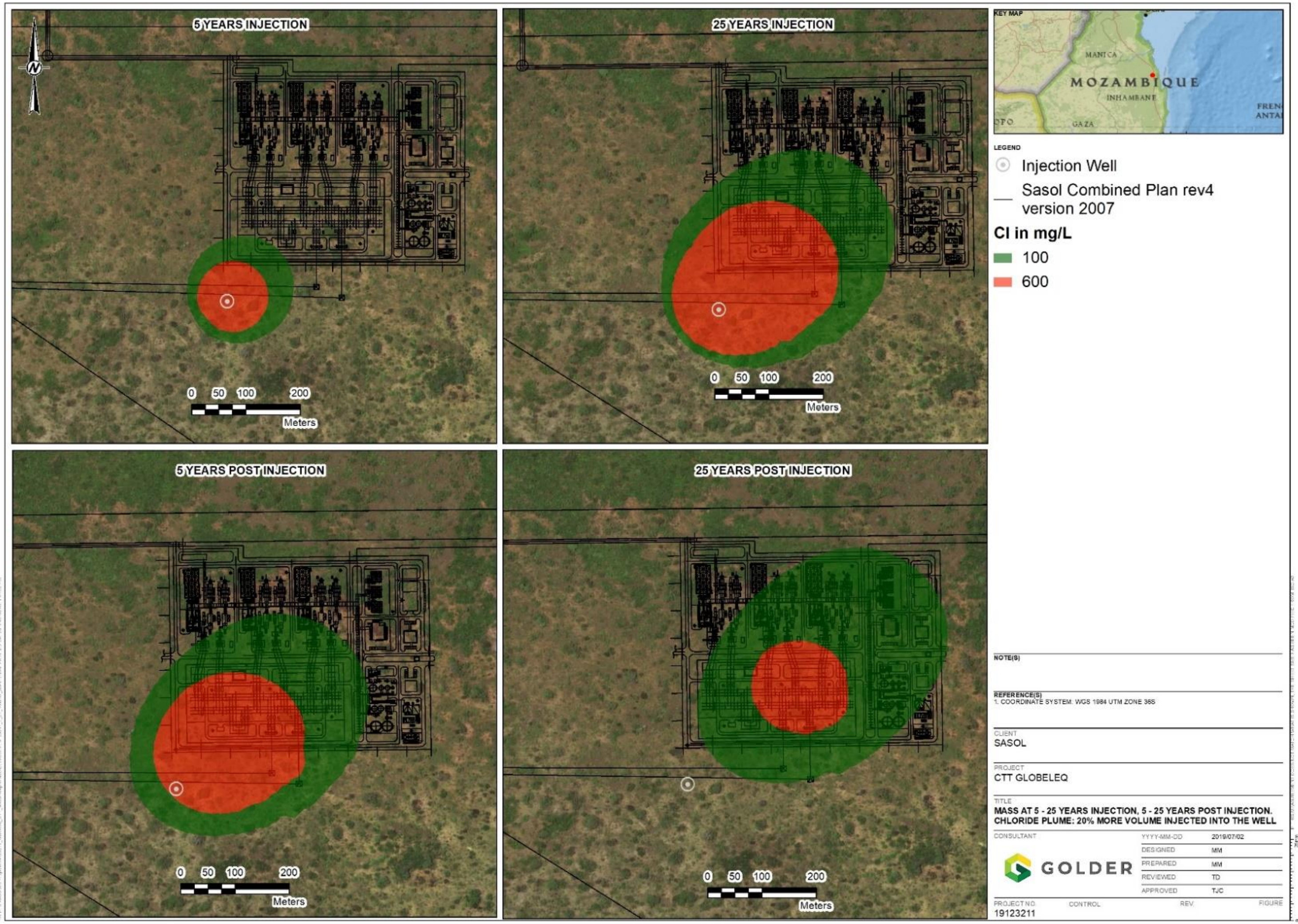

Figure 10: Simulated chloride plume at 5 and 15 years during injection and 5 and 25 years post-injection with 20% injection volume and concentration (750mg/L)

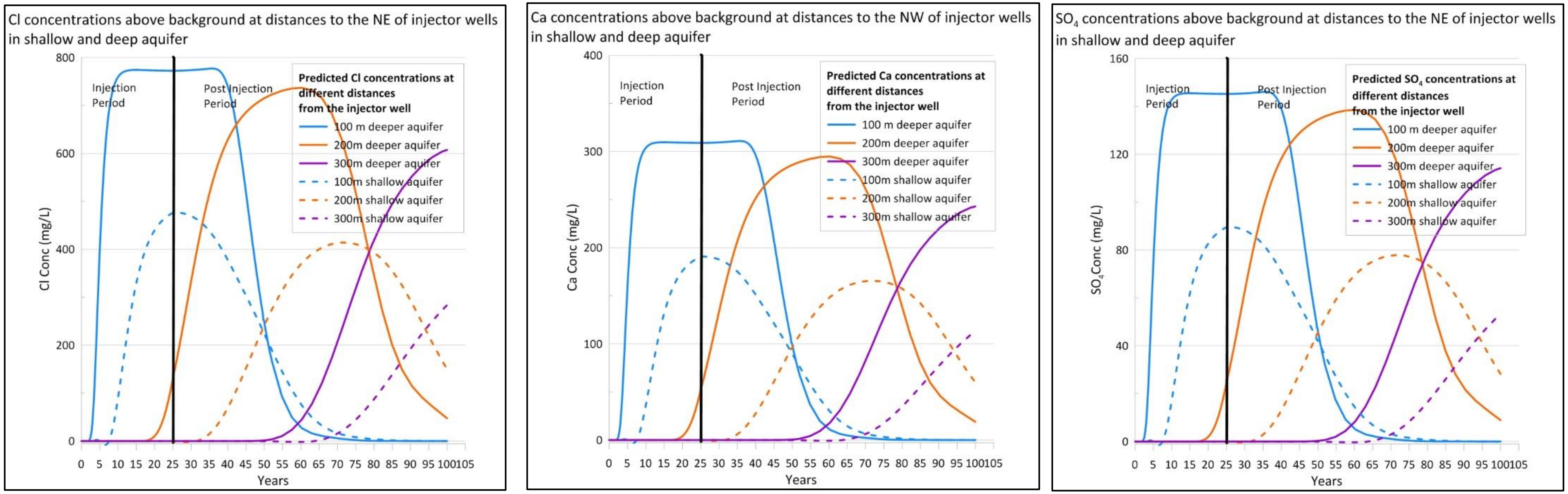

Figure 11: Graphs showing the anticipated increase in chloride (Cl), calcium (Ca) and sulphate (SO_4) concentrations in the shallow and deep aquifer at points 100, 200 and 300m down gradient of the injection well along Line A-B (Figure 4) (Using the 20% increased concentration for Cl, Ca and $S0_4$ concentrations)

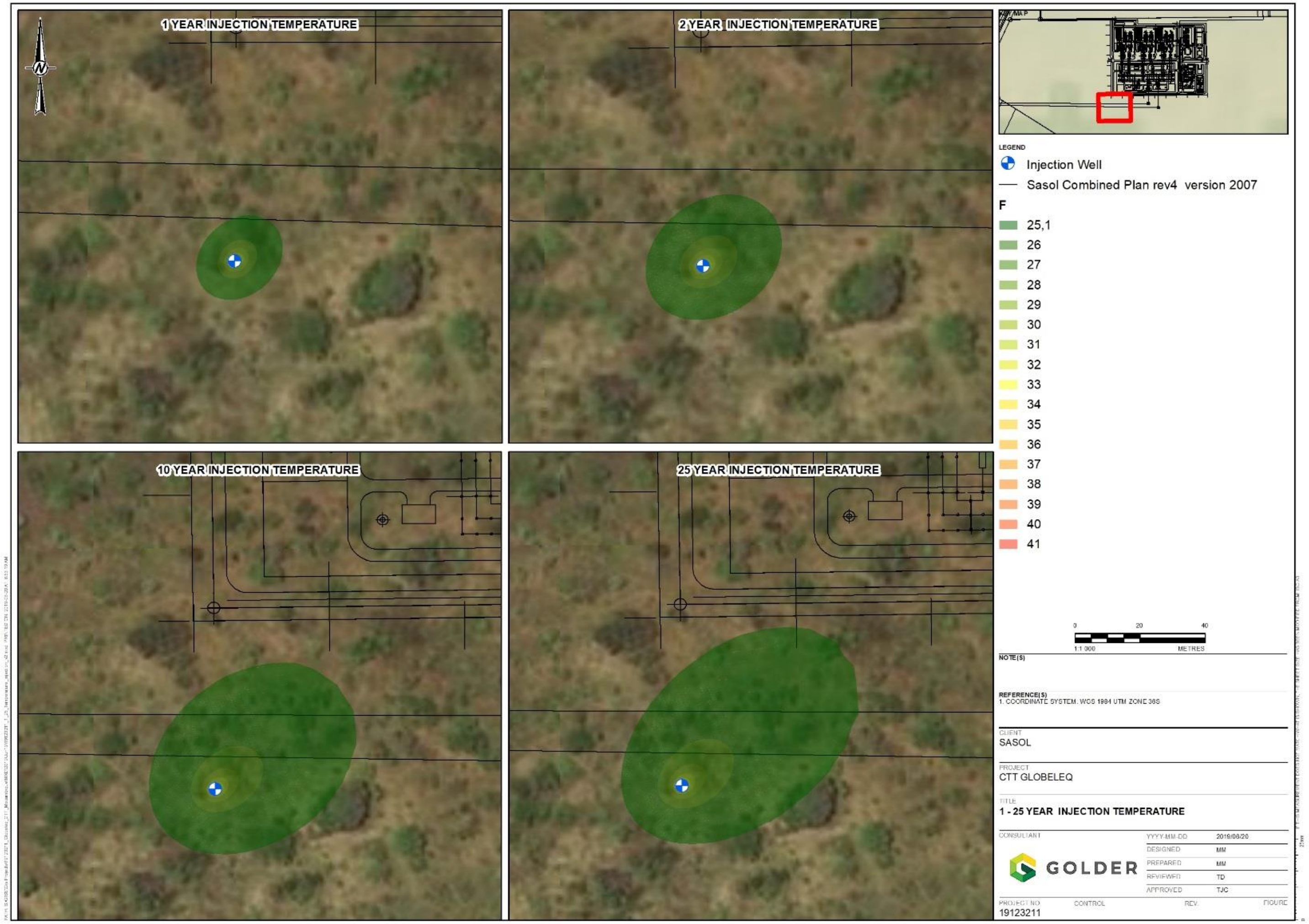

Figure 12: Snapshots in time of groundwater temperature around the of deeper aquifer injection of the CTT plant effluent at 42 °C

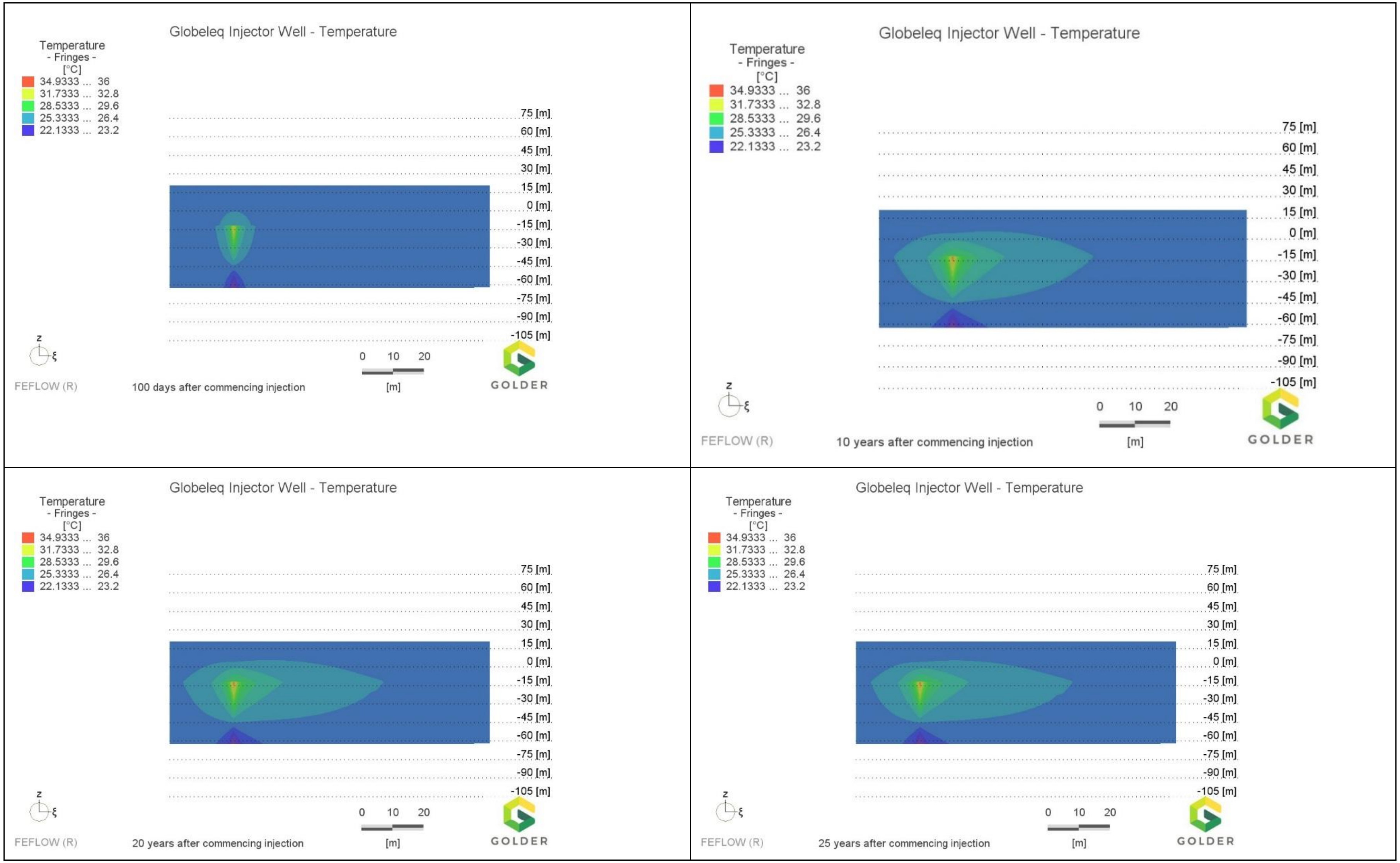

Figure 13: Snapshots of simulated groundwater temperature changes as a result of 42 injection of effluent into the well over 25 years along Line C-D

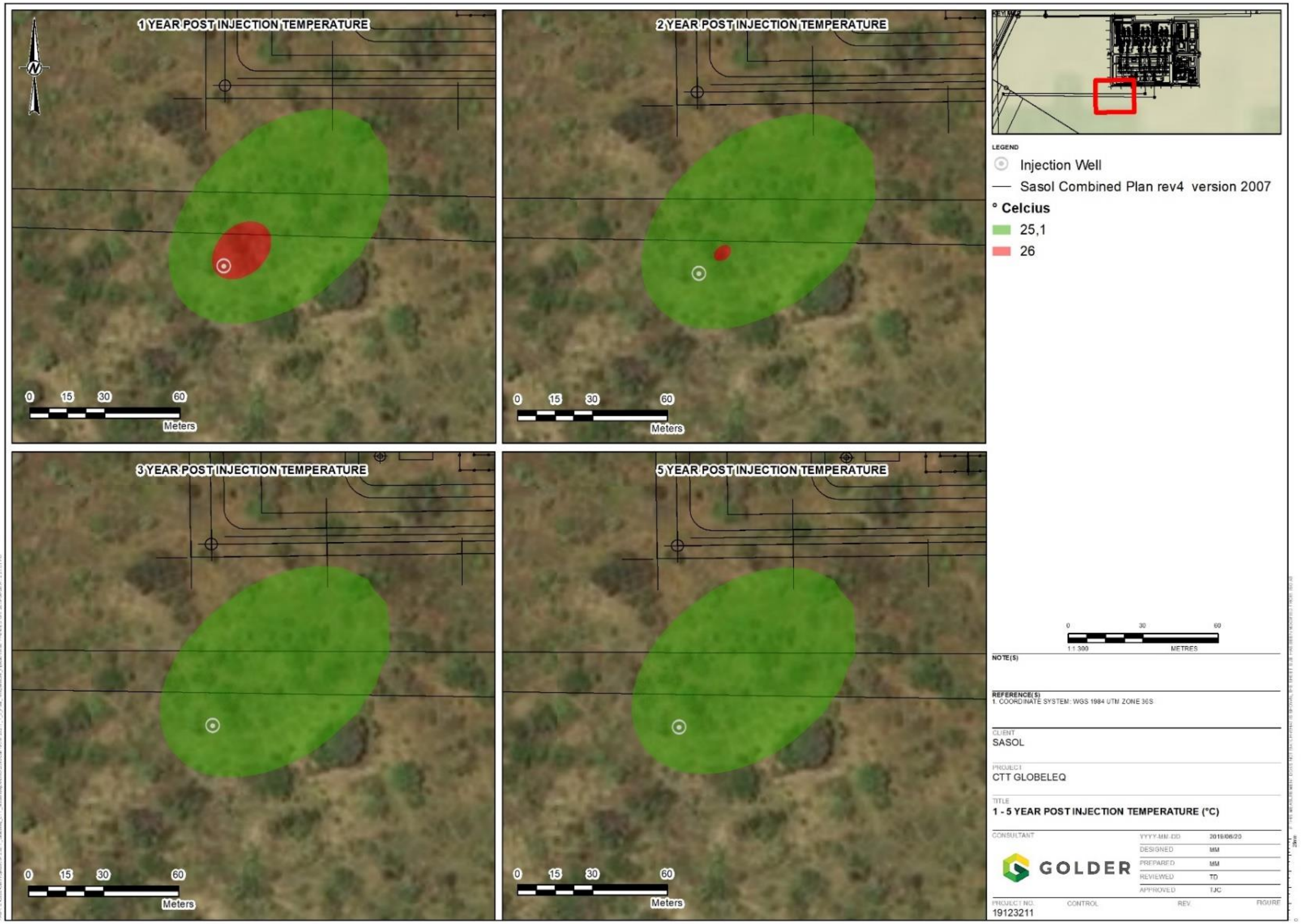

Figure 14: Snapshots in time of temperature around the of deeper aquifer CTT plant effluent injection well after thermal effluent injection has stopped

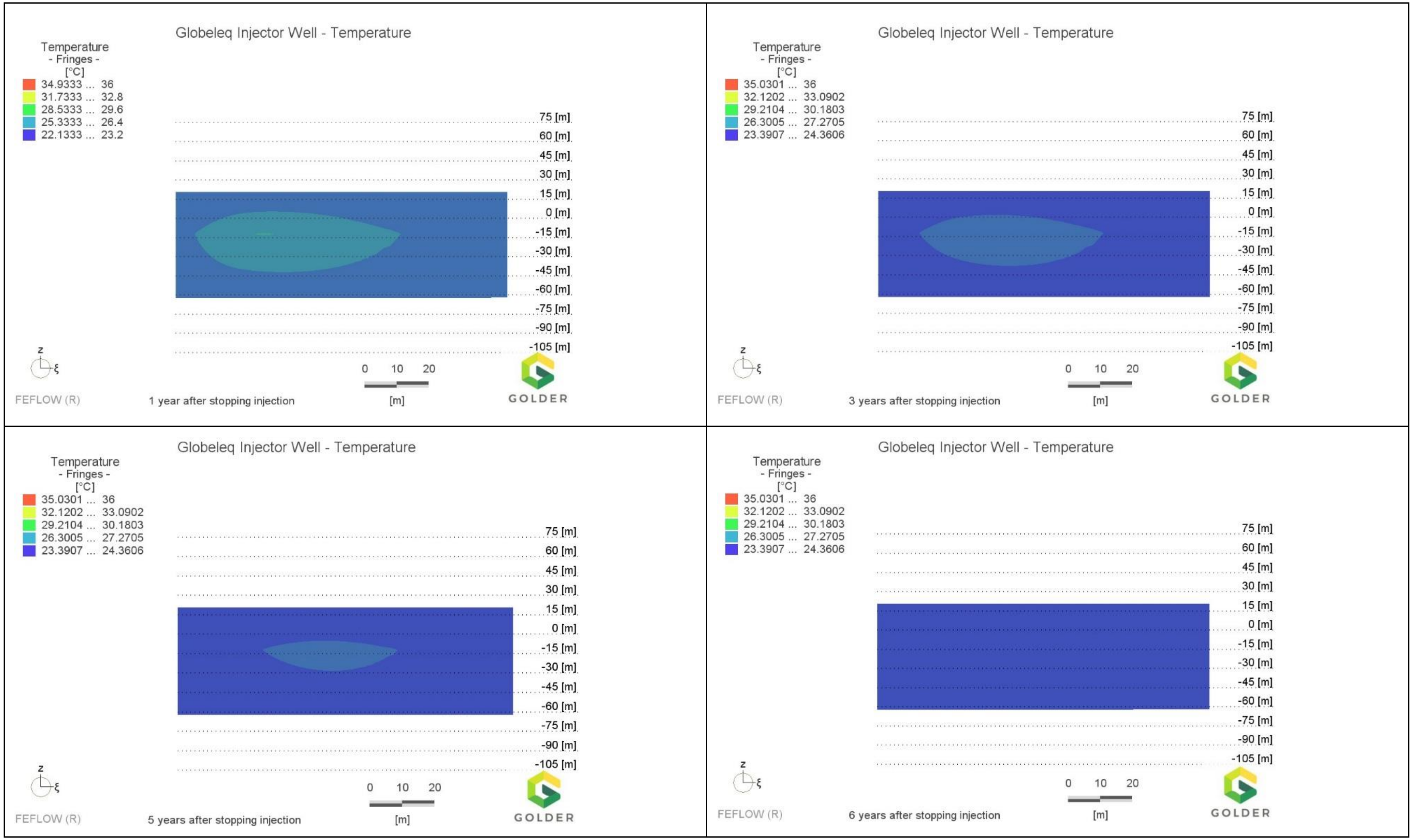

Figure 15: Snapshots in time simulated temperature of the groundwater around the CTT plant effluent injector well for up to 6 years after injection has stopped along Line C-D

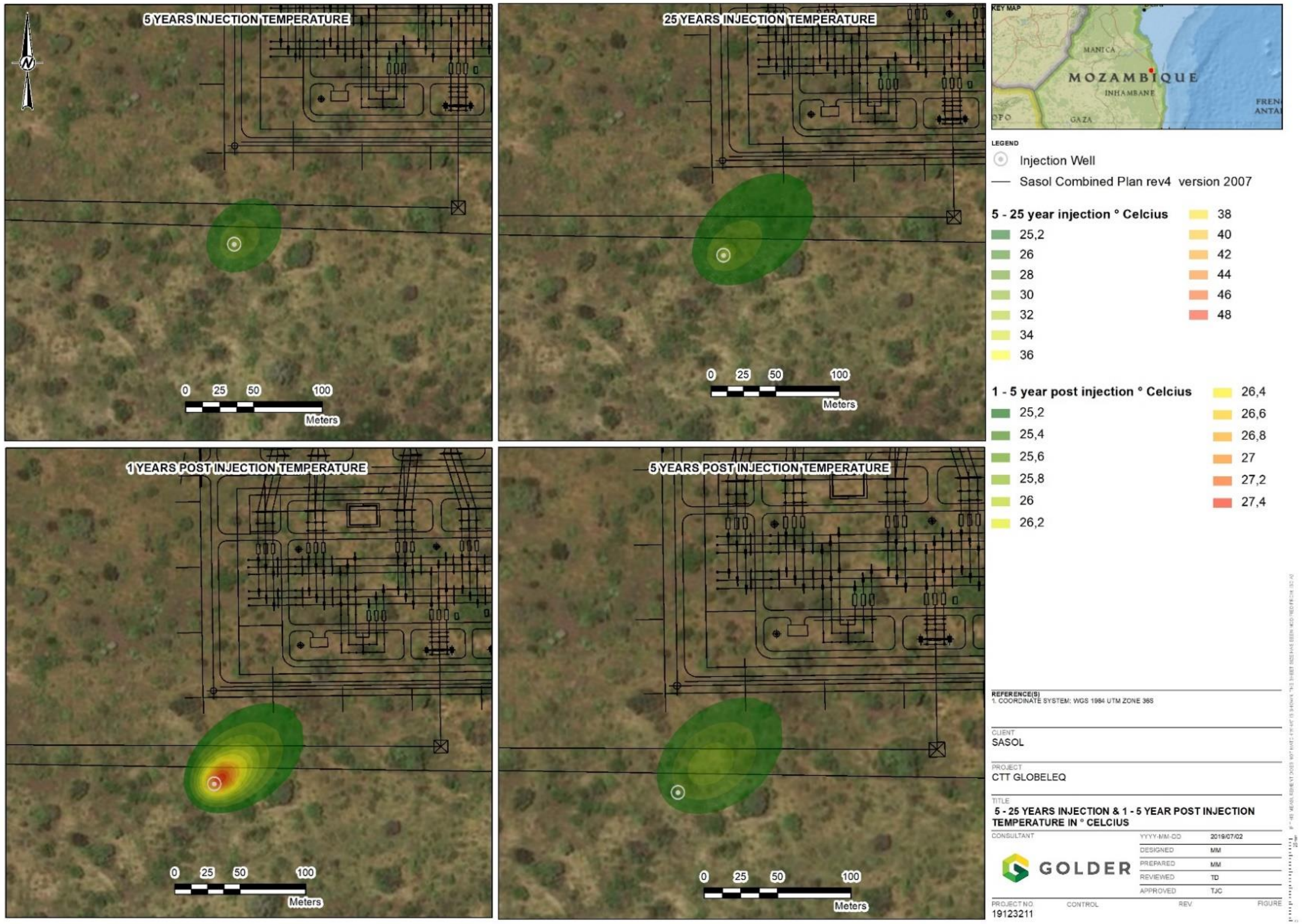

Figure 16: Simulated temperature contours in the deeper aquifer assuming a 20% increase in injected effluent discharge temperature

7.2 Option 2: Surface Discharge - Irrigation of Effluent

The second option of CTT effluent disposal considered is via irrigation to a 50-hectare pivot irrigation area scenario. Using the discharge criteria of available water quality and volumes of the combined effluent streams, the simulated irrigation of the effluent has assumed a chloride concentration of 480 mg/L and a constant irrigation rate of 36 m^3/hour, due to the mixing with source well quenching water.

Table 7 presents the quality of the irrigation effluent (based on dilution with the source well quenching water).

Table 7: Quality of irrigation effluent

Constituent	mg/l	Pot. Load: kg/m^3	SAR
TDS	1388.7	1.39	~2.21
Sodium	211.5	0.21	
Chloride	320.6	0.32	
Sulphate	60.3	0.06	
Calcium	130	0.13	

Figure 17 illustrates the development of a contaminant plume, represented by chloride concentration underlying the footprint of an arbitrarily selected irrigation field to the east of the proposed CTT plant footprint. It is assumed that the effluent irrigation occurs continuously for 25 years.

Figure 18 shows the simulated migration and slow dilution of the plume over a period of 50 years after irrigation on the irrigation footprint is stopped.

Mass concentrations of chloride of the contaminant plume are within the acceptable drinking water quality guidelines, posing no health risks.

Compliance to the Mozambican regulatory specifications for the use of water for irrigation, will require that moderate restrictions be placed on the use of the water, due to the elevated salt concentrations.

Direct irrigated water infiltration through the unsaturated loamy clay soil with an estimated hydraulic conductivity of 1e-5 cm/s, low and saturation of the sub-soil will develop over time containing a moderate to high salt load. Gradual salt build-up will result and given the poor infiltration rate of the soil, salinity will increase. The current sodium adsorption ratio class is a C1 (*i.e*. 2.21 meq/l) and regarded as having "*little or no hazard*", however, aeriation of the soil and soil leaching should be considered. The concentration of TDS in the water to be irrigated is classified as moderate and qualified as 'salty' which is considered as a risk to irrigation in terms of Mozambican regulations and requires moderate restrictions for irrigation. The SAR of the effluent irrigation water is however classified as low and is suitable for irrigation without restrictions (APPENDIX A).

Actual estimation of soil-unsaturated-zone permeability and depth to local groundwater level is required to assess the impact on the underlying groundwater resource by leaching. It is therefore required that a series of lysimeter and soil-infiltration tests are planned prior to designing an irrigation system to balance the plant's effluent discharge in this manner, should this option be implemented.

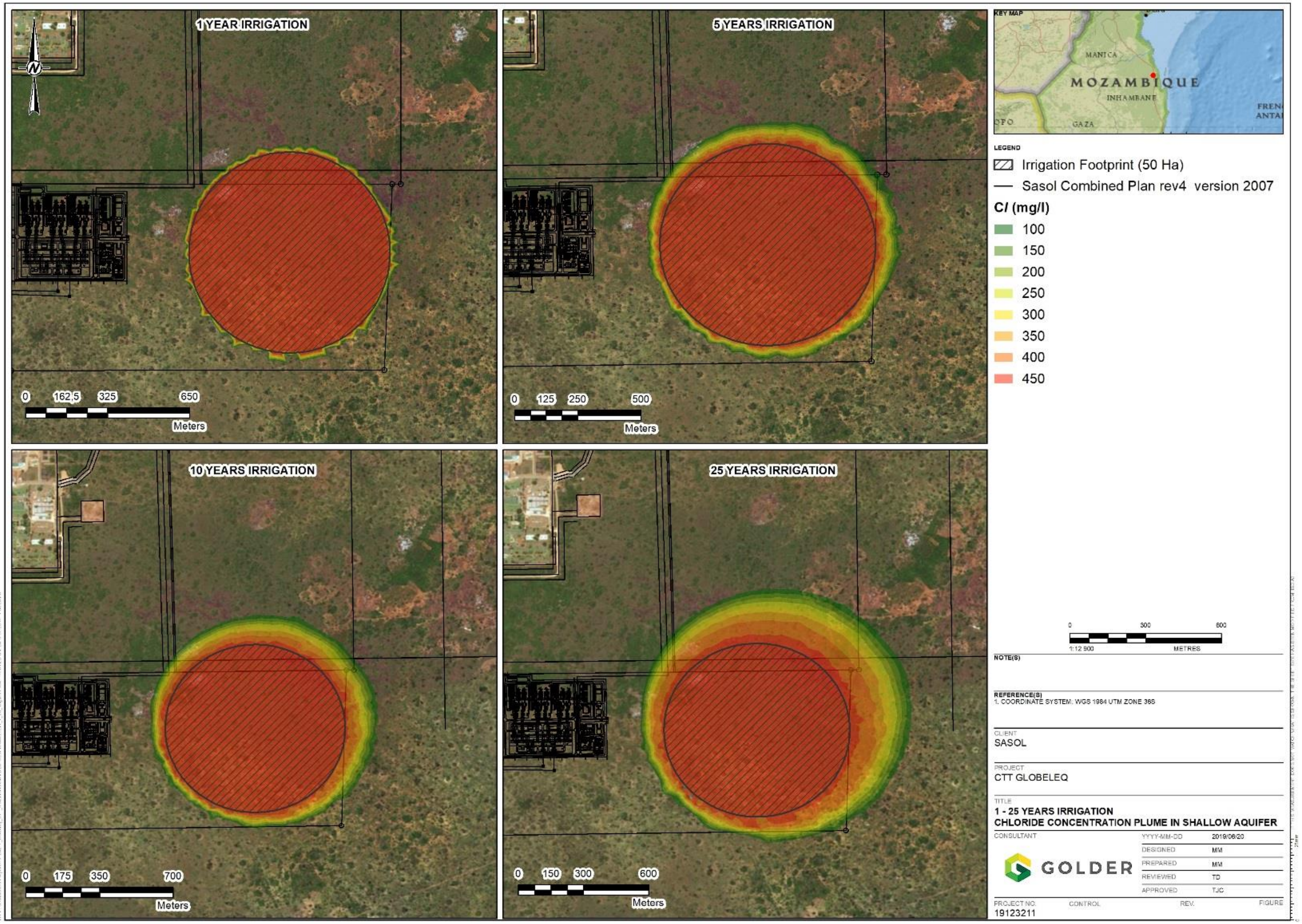

Figure 17: Snapshots in time of simulated chloride concentration over 25 years of continuous irrigation of CTT plant effluent on 50 ha irrigation field

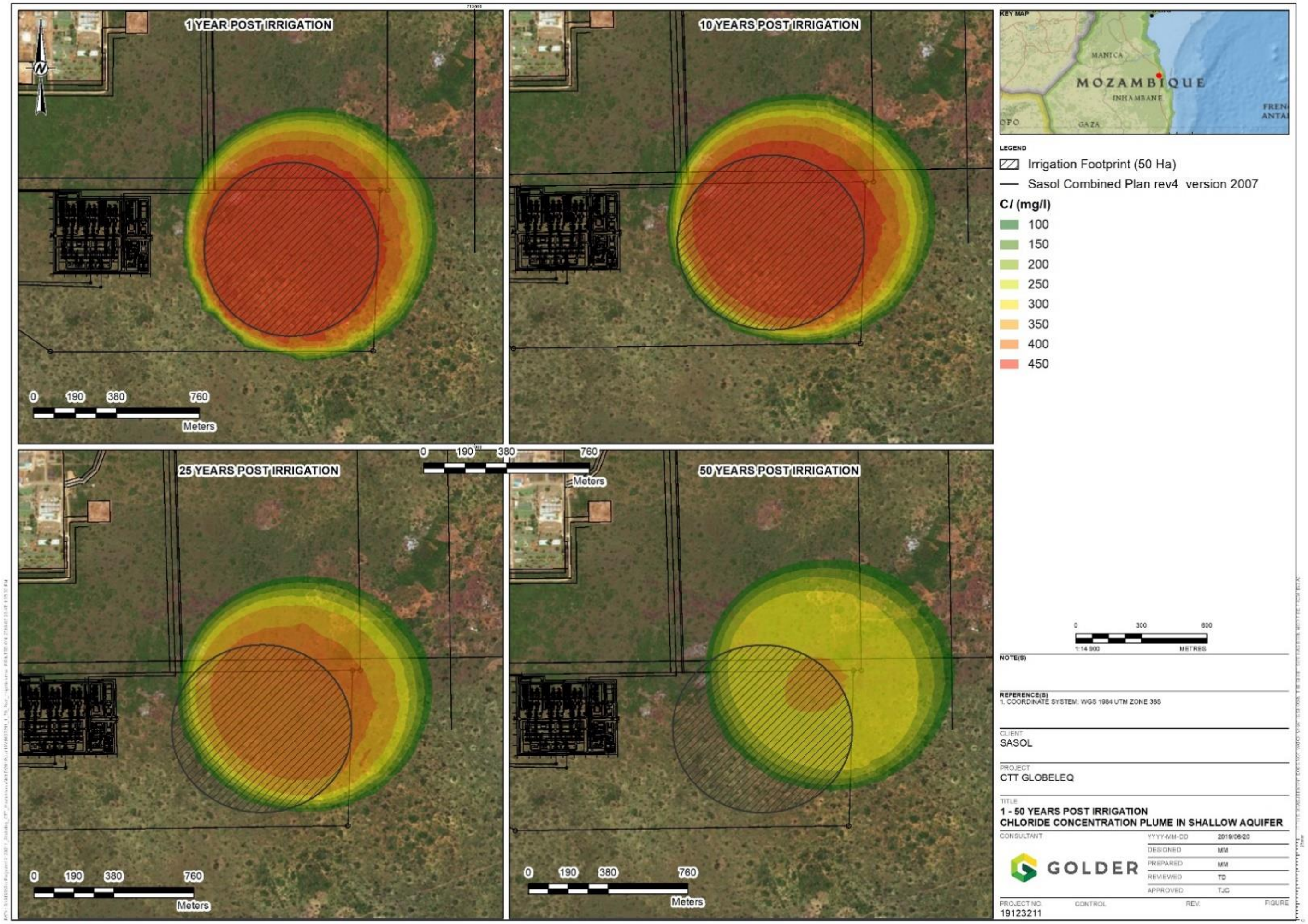

Figure 18: Snapshots in time of the simulated contamination plume after CTT effluent irrigation is stopped

8.0 COSTING OF OPTIONS

The costs provided are high level and suitable for the comparison of the options (at +/- 35% cost accuracy). Preliminary costs were determined based on previous experience and/or rates from potential suppliers. The median and upper range costs of the different options are included, as summary cost tables.

Capital costs were generated for all the options and they comprise of costs for civil infrastructure, mechanical, electrical, control and instrumentation equipment. Equipment budget prices were sourced from suppliers and were applied to generate the cost estimates.

The following is excluded from costing, and is assumed to be accounted for in site-wide or plant budgets:

- Fencing;
- Pumps;
- Access and service roads;
- Lighting;
- Control and instrumentation;
- OPEX (for the evaporation pond, irrigation and deep well injection).

Costing is South African based and has not been re-based for Mozambique to account for import of materials or localised construction rates. Conceptual designs were used to determine quantities for civil infrastructure that will need to be constructed on site. The cost estimates were based on limited information, at best reflecting the costs that can be assigned to the conceptual design.

8.1 Option 1: Aquifer Injection System

Aquifer injection wells for waste stream disposal are installed into the ground, away from the upper aquifers that feed drinking water sources. The availability of injection wells is geology dependent. An aquifer injection system comprises bored or drilled injection wells, that are deeper than their width. Well construction is dependent on the injection fluid injected and depth of the injection zone. The wells are designed with solid, multiple layers of protective casing and cement, to prevent the wastewater from mixing with the surrounding environment. The infrastructure is dependent on layers of pipe, surface casting, long string casing and injection tubing.

Due to the high salinity of the brine the following piping material is recommended;

- 316/314L Stainless steel
- Carbon steel

Option limitations:

- Corrosion or excessive feed pressure could result in a failure of the injection well casing and as a result leakage of brine through the well bore.
- Crystallization of brine salts in the pipe causing restricted flow and blockage.
- Vertical propagation of the brine outside of the well casing to the shallow aquifer.
- Nearby wells which are inappropriately cemented or plugged or have inadequate casing that could provide a pathway for the injected brine.

Other considerations:

- Requires confined aquifers that have a large storage capacity
- Avoid areas of high seismic activity or near geological faults.

Table 8 provides the high-level cost estimate for aquifer injection.

Table 8: High level cost estimate for Aquifer Injection

Option 1: Aquifer well inhjection		Amount (ZAR Excl. VAT)
Well (100 mm diameter) Depth (50m)		R 325,000.00
TOTAL (ZAR Excl. VAT, P & G and Contingencies)		**R 325,000.00**

8.2 Option 2: Surface Discharge by Irrigation

Irrigation of effluents is widely practiced and is a means to re-use water. Irrigation of effluents is an enhanced evapotranspiration system. Irrigation using a centre pivot system is conventionally used for irrigation of agricultural projects. A centre pivot system will also enhance direct evaporation into the atmosphere during sunny/windy days. This option could possibly include crops or vegetation (if feasible) to encourage evapotranspiration. A “mobile” centre pivot system is an option if more than one irrigation footprint needs to be developed.

Infrastructure/Materials:

- Pipeline from plant excess water sump to centre pivot, including centre pivot equipment complete.

Option limitations:

- Operating costs – electricity, spares and maintenance, labour.
- Failure of delivery pump, flooding from plant excess water sump
- Reduced effectiveness during winter months.

Table 9 provides the high-level cost estimate for surface discharge by irrigation.

Table 9: High level cost estimate for Surface Discharge by Irrigation

Option 2: Surface discharge by Irrigation		Amount (ZAR Excl. VAT)
Earthworks		R 2,879,467.52
Piping		R 417,800.00
TOTAL (ZAR Excl. VAT, P & G and Contingencies)		**R 3,297,267.52**

8.3 Option 3: Discharge to Evaporation Dams

Evaporation dams are the artificial solution to inland surface water discharge of waste effluents. Under the right climatic conditions, the water evaporates, allowing the discharge of more effluent streams to the dams. Evaporation dams are typically the final step in water treatment as there is no water reuse from the dam. The major consideration for the evaporation pond option is that they require large areas of land to increase the surface area where the water can evaporate.

The evaporation dam relies on solar (natural) evaporation. Surface area of dam is determined to balance incoming flow and direct rainfall with normal evaporation for the climatic region. Enhanced evaporation relies on solar (natural) evaporation assisted by enhanced evaporation using mist evaporator units. Surface area of the dam is determined to balance incoming flow and direct rainfall with normal evaporation plus assisted evaporation for the climatic region.

The application of the evaporation dams will require a significant space approximately 12 hectares for the handling of the effluent streams from the CTT plant over the lifetime of the project.

Infrastructure/Materials:

- Classic: Earthworks construction pond with lining system and soil layer to protect liner against warm water and paving to protect soil from erosion and allow clearance of sediment which may collect over time.
- Enhanced Evaporation: Earthworks construction pond with lining system and soil layer to protect liner against warm water and paving to protect soil from Additional concrete slab, pump and pipeline to feed excess water direct from plant through evaporator. Evaporator bypass water will drain into the pond for conventional evaporation.

Option limitations:

- Classic*:* High capital costs, large footprint area and climate change / extreme events / higher than average wet year can result in flooding and overtopping
- *Enhanced Evaporation:* Operating costs – electricity, spares and maintenance, labour, and climate change / extreme events / higher than average wet year can result in flooding and overtopping. Drift from the enhanced evaporation system is a potential environmental hazard.

Other considerations

- Differential settlement of earthworks across large area, rupture of liner;
- Reduced effectiveness during winter months, and
- Breakdown of equipment, lack of redundancy, overtopping of dam.

Table 10 provides the high-level cost for an evaporation dam and enhanced evaporation.

Table 10: High level cost estimate for Discharge to an Evaporation Dam

Option 3: Evaporation Dam		Amount (ZAR Excl. VAT)
Evaporation Dam		
Earthworks		R 11,869,868.00
Liner System		R 26,625,000.00
Top soiling		R 42,432.00
Grassing		R 91,936.00

Option 3: Evaporation Dam		Amount (ZAR Excl. VAT)
Paving		R 55,745,301.29
Piping		R 21,800.00
Miscellaneous		R 96,380.00
TOTAL (ZAR Excl. VAT, P & G and Contingencies)		**R 94,688,717.29**
Enhanced Evaporator		
2 X Evaporator (only)	Opex and Capex	R 1,769,466.88
TOTAL (ZAR Excl. VAT, P & G and Contingencies)		**R 1,769,466.88**

8.4 Option 4: Evaporative Crystallizer

Evaporative crystallization is a thermal evaporation method that offer a potential zero liquid discharge option for the blowdown water treatment. Thermal evaporation usually consists of a brine concentrator and crystallizer. The thermal evaporation and forced crystallizer system includes a crystallizer feed plate heater, a flash tank, a foam separator, a mechanical vapour compressor and a forced circulation heat exchanger. Two types of thermal systems may be applied based on their residual outputs: (1) evaporators that produce concentrated, low volume brine but do not precipitate solids; and (2) crystallizers that exceed salt saturation and produce solids. The final disposal of residuals is required and is important. Process reduces the volume of brine for disposal.

Variation in brine thermal evaporator system technology are available. The installation of evaporative crystallizer does not warrant the requirement evaporation pond if the selected technology includes crystallizers that exceed salt saturation and produce solids. However, if the output is the low volume brine, a significantly smaller brine disposal pond would be required or alternatively an off-site disposal option.

Infrastructure/Materials: The piping and ducting material requirements are as follows:

- Tanks and pumps;
- Feed pipeline;
- Reticulation piping around the crystallizer;
- Distillate piping;
- Steam piping;
- Other utility piping and chemical dosing piping;
- Other miscellaneous material may be constructed from Stainless steel or Carbon steel. Some of this material may need to be imported and are not locally supplied.

Option limitations:

- This option may require a large energy source dependent on the evaporator system used.
- High capital cost.

- Cost associated with this process is greater than the conventional brine treatment or disposal methods.
- The construction time may take 6-18 months.

Other Considerations**:**

- An inherently a safe approach.
- Mechanical vapour re-compressors are most common within the blowdown treatment as they do not require a continuous feed of steam (only requires start up steam and then is able to generate its own steam).
- Requirement for specialized skills required to design this process. This may need to be outsourced.
- Technology is versatile and can be retrofitted and designed for most wastewater treatment applications.
- Some of the construction materials may not be locally available.

Table 11 provides the high-level cost for an evaporative crystallizer.

Table 11: High level cost estimate for an Evaporative Crystallizer

Option 4: Evaporative Crystallizer		Amount (ZAR Excl. VAT)
Brine concentrator and Crystalliser only	Opex and Capex	R 66,182,878.44
TOTAL (ZAR Excl. VAT, P & G and Contingencies)		**R 66,182,878.44**

8.5 Cost Estimate Summary

The cost estimates of the proposed effluent discharge options are summarised in Table 12 below:

Table 12: Summary of cost estimates

Option		Cost estimates
1	Deep well aquifer injection	R 325,000.00
2	Surface discharge by irrigation	R 3,297,267.52
3	Evaporation dam	R 94,688,717.29
	Enhanced evaporator (only)	R 1,769,466.88
4	Evaporative crystallizer	R 66,182,878.44

9.0 CONCLUSION

The existing groundwater model constructed by Golder using FEFLOW in 2018, was updated to include a steady state calibration and an adjustment of hydraulic parameters and recharge rates. The resulting K values used in the calibrated model are much lower regionally and more range with values suggested by Rison Consulting (2019).

The general groundwater flow directions in the area of interest are from the higher lying areas in the south-west towards the north-east and towards the Govuro River.

The results from the modelling suggest that injection of the high salt effluent into the lower karst aquifer will only have a limited impact from both a quality and temperature perspective, and a low risk to human health of downstream water users. The effluent is diluted over time and migration of the plume is limited to 300 -500m of the injection well over the 100year period modelled, due to the low gradient. Injection of the high salt effluent into the lower aquifer will also limit the impact on soils and subsoils and require a lesser amount of infrastructure. The position of the injection well upgradient of the proposed CTT plant will also maximise the time for dilution of the plume in the groundwater before it migrates off site towards the north east.

With respect to the irrigation of the effluent, the modelling suggests that there will be a moderate impact on the groundwater quality. There is migration and slow dilution of the plume over a period of 50 years after irrigation on the irrigation footprint is stopped. Mass concentrations of chloride of the contaminant plume are within the acceptable drinking water quality guidelines, posing no health risks. However, irrigation of the effluent will require environmental authorisation to comply with Mozambican standards and will include certain restrictions be placed on the activity.   Actual estimation of soil-unsaturated-zone permeability and depth to local groundwater level is still required to assess the impact on the underlying groundwater resource by leaching.

The disposal of the effluent through an injection well is the most cost-effective option, followed by irrigation, which is approximately at a 10-fold higher cost.

10.0 RECOMMENDATION

Although it is anticipated that the impact of the injection of the high salt effluent at the proposed concentrations and volumes is considered low, monitoring of the actual concentrations of the groundwater prior to the commencement of effluent injection at the proposed site and 50, 100 and 300m downgradient (north east) is recommended in order to ascertain baseline conditions. Groundwater sampling in all 3 down-gradient locations should continue regularly in order to monitor whether the breakthrough curves as illustrated in Figure 11, reflect reality.

Continuous monitoring of electrical conductivity in the monitoring boreholes could significantly improve the understanding of the contamination plume migration and dilution effects of the aquifer on the plume.

Installation of water abstraction boreholes may affect the migration of the contamination plume over time.

Signature Page

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APPENDIX A

Environmental Quality Standards and Effluent Emission - Appendix VI - for Effluent to be used for Irrigation

Electrical Conductivity of Water

Electrical Conductivity in mS/cm				
Min	**Max**	**Classification**	**Qualification**	**Interpretation**
0.1	0.25	Very low	Non-salty	Without restrictions for irrigation
0.26	0.75	Low	Little salty	Little risk for irrigation with moderate leaching
0.76	2.25	Intermediate	Salty	Risk for irrigation: use the water on soils moderately to poorly permeable and sowings with intermediate to good tolerance to salinity: leaching is necessary
2.26	4	High	Highly salty	High risks for irrigation: use water on well permeable soils and sowings tolerant to salinity, “necessary special leaching conditions”
4.01	6	Very High	Extremely salty	Undesired irrigation: only on soils highly permeable and sowings highly tolerant to salinity
>6.00		Extremely high	Excessive salty	Water not suitable for irrigation, only in very special conditions

Maximum Electrical Conductivity of Irrigation Water (mS / cm) in the Light of the Texture

EC paste (soil)	Soil texture				
mS / cm	**Sand**	**Frank-sandy**	**Frank**	**Frank-clayey**	**Clay**
< 4.0	2.5	1.6	0.8	0.8	0.4
4.1 – 10.0	6.5	4	2	2	1
> 10.0	10	6	3	3	1.6

pH and Cations and Anions Content of Irrigation Water

Ion	Symbol, unit	Degree of restriction		
		None	**Moderate**	**Severe**
Calcium	Ca2+, meq / l	Normal interval 0 – 20		
Magnesium	Mg2+, meq / l	Normal interval 0 – 5		

Ion	Symbol, unit	Degree of restriction		
		None	**Moderate**	**Severe**
Sodium and Chloride	Na+ and Cl-, meq / l	Sprinkler		
		< 3	< 3	
Chloride	Cl-	Gravity irrigation		
		< 4.0	4.1 – 10.0	> 10
Carbonate	CO3 2-, meq / l	Normal interval 0.0 – 0.1		
Bicarbonate	HCO3-, meq / l	Sprinkler		
		< 1.5	1.5 – 8.5	> 8.5
Sulphate	SO4 2-, meq / l	Normal interval 0 – 20		
Nitrate	N-NH3-, mg / l	< 5	5 -30	> 30
Ammonia	N-NH4+, mg / l	< 5	5 - 30	> 30
Phosphate	P-PO4 3-, mg / l	Normal interval 0 – 2		
Potassium	K=, mg / l	Normal interval 0 – 2		
Boron	B, mg / l	< 0.7	0.8 – 3.0	> 3.0
pH		Normal interval 6.5 – 8.4		

Soluble Salts (g/litres)

Min	Max	Classification	Qualification	Interpretation
0.0	0.2	Low	Little salty	Useful for irrigation
0.3	0.5	Intermediate	Moderately salty	Useful for irrigation with moderate leaching, sowings with a moderate tolerance to salinity
0.6	1. 5	High	Very salty	Restrictions for soils poorly drained, sowings shall be tolerant to salinity
> 1.5		Very high	Extremely salty	Not suitable for irrigation in ordinary conditions. Soils shall be permeable, adequate drainage, excessive irrigation, with considerable leaching and sowings highly tolerant to salinity

Min	Max	Classification	Qualification	Interpretation
> 6.00		Extremely high	Excessively salty	Water not suitable for irrigation, only in very special conditions.

Sodium-Adsorption Ratio (SAR) of Irrigation Water

Min	Max	Classification	Qualification	Interpretation
0	10	Low	Good	Suitable for irrigation, without restrictions
11	18	Intermediate	Moderate	Problematic in soils with fine texture, with low leaching speed, except if the soil has plaster. Water may be used in soil with coarse texture or well permeable organic soils
19	26	High	Bad	Problematic in most of the soils. Possible irrigation of soils containing plaster.
> 26		Very high	Very bad	Generally not suitable for irrigation

Total of Dissolved Solids, mg / litre

Min	Max	Classification	Qualification	Interpretation
0	450	Low	Optimum	Without restrictions for irrigation
451	2000	Intermediate	Moderate	Moderate restrictions for irrigation
> 2000		High	Bad	Severe restrictions for irrigation

IFC water effluent requirements for irrigation purposes

Parameter	Unit	Degree of restriction		
		None	Slight to Moderate	Severe
Salinity – Electrical conductivity EC_w at 25 C	dS/m	< 0.7	0.7 – 3.0	> 3.0
TDS	mg/l	<450	450 – 2000	>2000

Parameter	Unit	Degree of restriction		
		None	Slight to Moderate	Severe
TSS	mg/l	<50	50 – 100	>100
SAR (Sodium adsorption Ratio) (0-3)	meq/l	> 0.7 EC_w	0.7–0.2 EC_w	< 0.2 EC_w
SAR (3–6)	meq/l	> 1.2 EC_w	1.2-0.3 EC_w	< 0.3 EC_w
SAR (6-12)	meq/l	> 1.9 EC_w	1.9-0.5 EC_w	< 0.5 EC_w
SAR (12-20)	meq/l	> 2.9 EC_w	2.9-1.3 EC_w	< 1.3 EC_w
SAR (12-20)	meq/l	> 5.0 EC_w	5.0-2.9 EC_w	< 2.9 EC_w
Sodium (Na^+) – sprinkler irrigation	meq/l	< 3	> 3	
Sodium (Na^+) – surface irrigation	meq/l	< 3	3-9	> 9
Chloride (Cl^-) – sprinkler irrigation	meq/l	< 3	> 3	
Chloride (Cl^-) – surface irrigation	meq/l	< 4	4-10	> 10
Chlorine (Cl_2) – Total residual	mg/l	< 1	1-5	> 5
Bicarbonate (HCO_3^-)	mg/l	< 90	90-500	> 500
Boron (B)	mg/l	< 0.7	0.7-3.0	>3.0
Hydrogen sulphide (H_2S)	mg/l	< 0.5	0.5-2.0	> 2.0
Iron (Fe) – Drip irrigation	mg/l	< 0.1	0.1-1.5	> 1.5
Manganese (Mn) – Drip irrigation	mg/l	< 0.1	0.1-1.5	> 1.5
Total nitrogen (TN)	mg/l	< 5	5-30	> 30
pH	mg/l	Normal range 6.5 - 8		

APPENDIX B

Document Limitations

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