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Comoros Geothermal Project: Exploration Drilling Infrastructure Assessment

Adaïne Anlil-wafa, Mohamed Chaheire, Keith Swedhin and Mauricio Taulis

Geological Bureau of Comoros, Ministry of Energy – BP 8083 – Moroni – Union of the Comoros

lilwafa03@gmail.com

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ABSTRACT

Studies on the total geothermal energy potential of the Karthala volcano are promising. This is based on the surface exploration studies carried out between October 2014 and August 2015. From the results of the surface investigations, the Karthala summit area has the capacity to generate 45 MWe mainly for electric power production.

The Government of Comoros is planning to develop 10 MWe of geothermal power during the first phase. However, development of this phase is not devoid of challenges such as infrastructural requirements for the exploration drilling. This study involves assessing port facilities, existing road network and access to the proposed site, and reviewing options for water supply for drilling.

A water supply study was undertaken to assess various options for supplying the drilling operations with adequate water during the exploratory drilling phase. Several water supply options have been identified (groundwater abstraction, surface capture and seawater capture) but groundwater catchment is identified as the best solution for water supply exploratory drilling.

MT data analysis and interpretation enabled us to locate ground water reservoirs north of Karthala with flow rates sufficient for exploration drilling activities.

This study allowed us to review infrastructure requirements and develop cost estimates

1. INTRODUCTION

Surface exploration studies for the Comoros geothermal project began in October 2014 and ended in August 2015. Based on the positive indications from the surface exploration, the GRMF has offered support of 40% towards the cost of exploration drilling for three full size deep wells and a GEF grant is also available, covering some 32% of anticipated expenditure of the exploration phase.

In addition to the committed funding, the project is seeking US$36.2 Million to establish project infrastructure, for access and water supply, and to undertake the drilling work that is essential to confirm the presence of an exploitable resource.

In order to support the Comoros project, the government of New Zealand has engaged Jacobs to provide on-going technical assistance and complete several work packages, including an infrastructure assessment for the exploration drilling phase.

Two sites have been identified as most favorable for locating drilling pads. It is proposed three full-sized, deviated exploration wells be drilled from these two well pads under which the estimated geothermal resource lies.

The purpose of this study is to assess the suitability of existing port, roading, plant and utility infrastructure on Comoros in order to assess the viability and costs for accessing drilling locations and completing an exploration drilling program. Also, review the Grande-Comore Water Supply Study.

2. EXISTING INFRASTRUCTURE ON GRANDE-COMORE

2.1 Port of Entry

The main port of entry to Comoros is the Moroni Terminal on Grande Comore. The main dock is located in Moroni and caters to commercial and industrial cargo entering Comoros. A small pier is located to the east of the Terminal; this caters to a very limited amount of tourism related marine traffic. However the Moroni Terminal compound has adequate wharf frontage and wharf area for container and general cargo storage; container stacking was practiced. The port have satisfactory security and access to good haul routes to the site.

The port's management is confident that the Terminal had the capacity to receive and provide temporary storage for the estimated 90-110 containers that would be delivered for the proposed geothermal exploratory and production drilling operations.

2.2 Assessment of Existing Road System from Moroni to Bahani

Through a desktop study of the island's existing road network and topography, it was determined that Bahani would be the best point to transition from existing roads to a new access road up to the drill site. This was due to multiple major roads (RR101, RN4, etc) connecting a nearby, relatively high elevation area to the Moroni Terminal. The existing topography between Bahani and the drill site was generally sloped favourably while being able to utilize an existing 4WD trail through the more challenging terrain.

The general condition of the road from the port is good and Bahani is approximately a 30 minute drive from the Port under typical "non-peak" traffic patterns.

2.3 Access to Site from Bahani

The access route from Bahani and drilling site was determined based on indicative vegetation extents and current topography. This route is minimally developed and approximately 15km long (figure 1).

The first 4.2 km section extending east from the public road near Bahani is an existing 4WD vehicle trail (yellow line in Figure 1). It will need to be upgraded by both widening to two lanes and stripping the top surface to approximately 150 mm depth and then rebuilding using 150 to 300 mm of Subbase material with 150 mm of base/wearing course. At least two sections of this 4WD trail will need to be further evaluated for adequate width to accommodate two lanes for haul trucks (Photos 1).

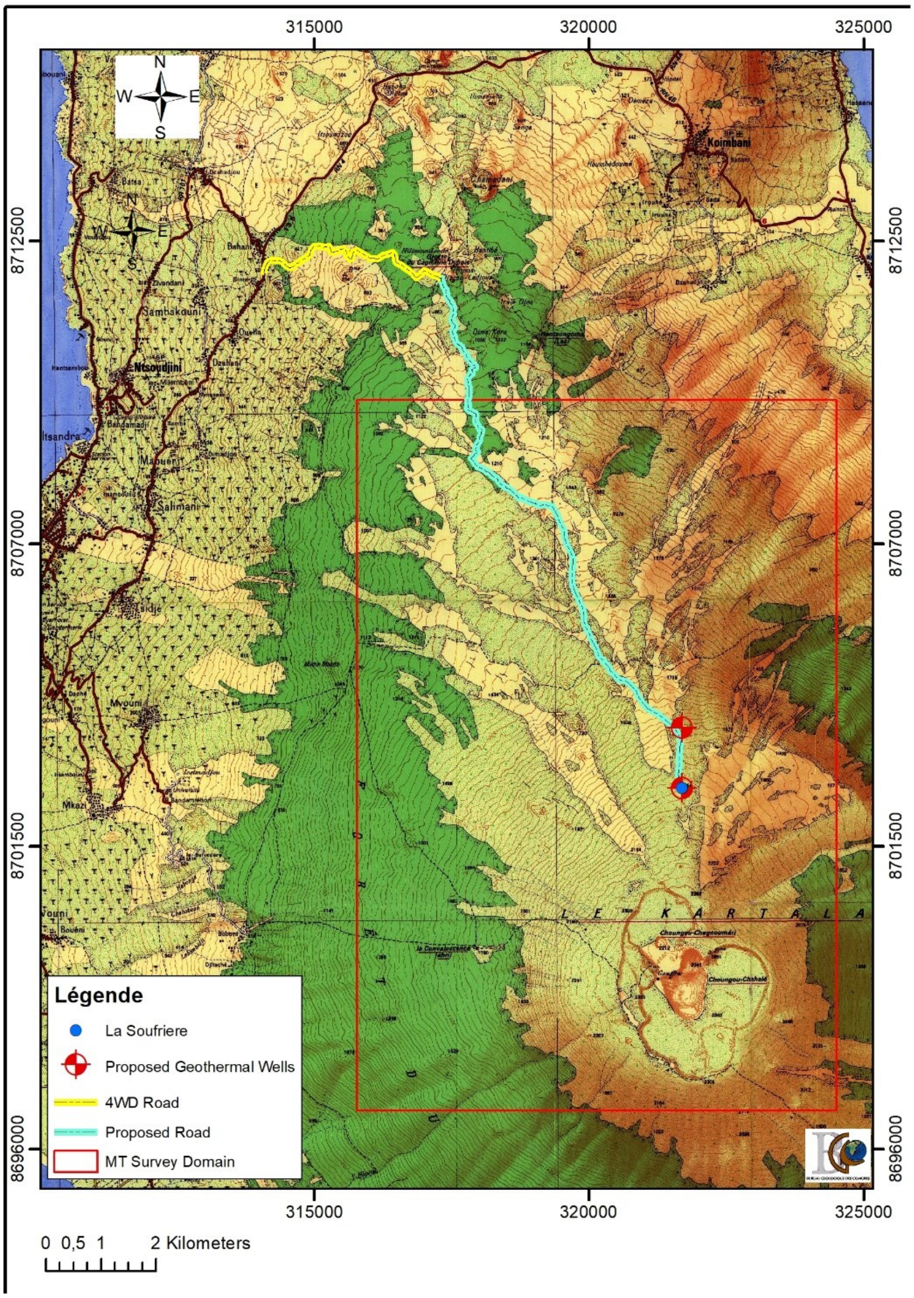

Figure 1: Map showing approximate route from Bahani to well pad locations.

The second section to the drill site is 10.6 km long (blue line in figure 1) and will be a wholly new road requiring route identification, de-vegetation, and constructing a new surface similar to the upgrades identified for the 4WD vehicle trail. This section of the route will need to be constructed through a small portion of existing forest and historical lava flow areas. The topography for the uppermost 2-3 km display existing slopes up to 5:1 (20%) which exceed the desired 6:1 (16.5%) for truck haul routes.

The drilling sites are located in gradually sloped areas that with some earthworks could be suitably developed.

Photo 1: Typical condition of 4WD vehicle road.

3. WATER SUPPLY FOR DRILLING

3.1 Study Area

The Karthala massif covers the central and southern areas of Grande Comore and is currently the only active volcano on the island. The Karthala volcano hosts an active hydrothermal system.

The red rectangle in Figure 1 shows the main study area for this investigation. Magnetotellurcis (MT) survey data was obtained through the stations located throughout the study area within the inland domain. To date, no actual drilling has taken place within the inland domain. Creating a 3D model based on the MT data will help conceptualise the deep water table and rock units. This 3D model will enable the development of an exploration programme and a water production assessment based on calculations of potential well yield. In addition, a basic surface water catchment model will be created for selected catchments within this area to determine whether it will be feasible to use surface water as a potential water supply option.

3.2 Geothermal Exploration Program

The Comoros geothermal exploration program consists of drilling deep wells to produce geothermal energy. The proposed scheme includes drilling three geothermal wells with depths between 2,500 – 2,900 m BGL over a 60-day period. Figure 2 shows the design of the wells being drilled from two well pads; two wells will be drilled at Pad A and one well from Pad B

Reliable water supply for exploration drilling will be required to complete the drilling program. The actual water requirements will be strongly influenced by the drilling conditions encountered and will vary depending on the stage of drilling. An estimated breakdown of water requirements over time is given in Table 1.

Typical storage of water at the drilling sites will be within an excavated drilling reservoir with a nominal size of 8,000 m3 for standard sized well designs. This is a typical pond size for geothermal operations. This sized reservoir can sustain 44 hours drilling blind without replenishment.

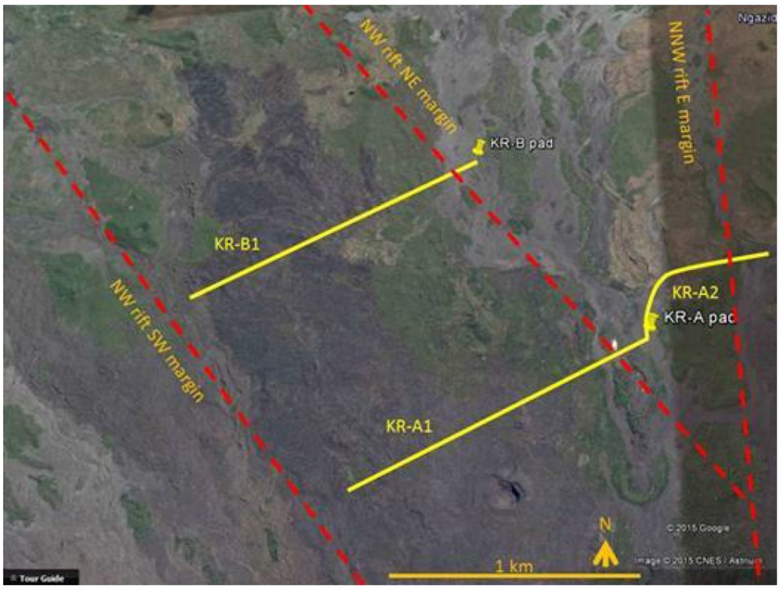

Figure 2: Drill pad design.

Table 1: Estimated water supply requirements for drilling a standard sized well to 2,500 mBGL (Jacobs, 2017).

Standard Sized Well	Day 1-47	Day 47-60
Average water demand (m3/day)	240	4,320
Quench demand (m3/day)		2.400[1]
Total volume (m3)	11,300	56,200
Note: [1] Quench demand is for a period of 12 hours only (NZS2403:2015 Code of Practice for Deep Geothermal Wells). This is the minimum volume of water that should be available to quench the well for a continuous period of 12 hours when no back-up water supply pump is available (e.g. quenching by gravity).		

Therefore, this study has been realized by assuming scenarios for construction of either an 8,000 m3 or 16,000 m3 capacity storage reservoirs. The replenishment rates for these reservoirs have been determined by assuming actual (dynamic demand) scenarios as well as maximum or worst case scenarios (e.g. 3,000 m3/day and 5,000 m3/day). Table 2 outlines a summary of the drilling program and water requirements used within this study.

Table 2: Drilling program and water requirement overview (Jacobs, 2017).

Description	Amount Required
Number of geothermal wells	3
Drilling period	60 days per well; 2 weeks downtime between well sites for
Reservoir size	8,000 m3 or 16,000 m3
Water demand for drilling	3,000 m3/d (34.7 L/s) or 5,000 m3/d (57.9 L/s)
Dead storage requirement (reservoir)	5,000 m3

3.3 Object of the water supply study

The objective of this Water Supply study is to assess the water supply capacity and feasibility associated with the water supply options. This is achieved through modelling selected scenarios using available data.

There are two options available to satisfy the water requirements for the Comoros geothermal exploration program: surface water abstraction or installation of groundwater production wells. Thus a surface water supply model has been elaborated. The aim of this model is to determine whether Surface Water abstraction or Groundwater production are viable supply options.

3.4 Hydrogeology of the Study Area

The overall impression of the thermal activity at Karthala is of a young magmatic-driven geothermal system recharged by meteoric water with no evidence of seawater input. There is a strong evidence for the existence of a high-temperature resource (up to 290°C) where liquid and vapor seem to coexist (Jacobs, 2014).

Significant precipitation falls on the summit of the Karthala volcano, especially on the northern and southwest flanks. During precipitation events, water is able to easily infiltrate through the volcanic lavas and scoria due to high permeability. The infiltrated water is expected to sit within perched aquifers and could possibly be a reliable source of water for the drilling program. Water infiltration is evident as the water level fluctuates within the lake at the summit.

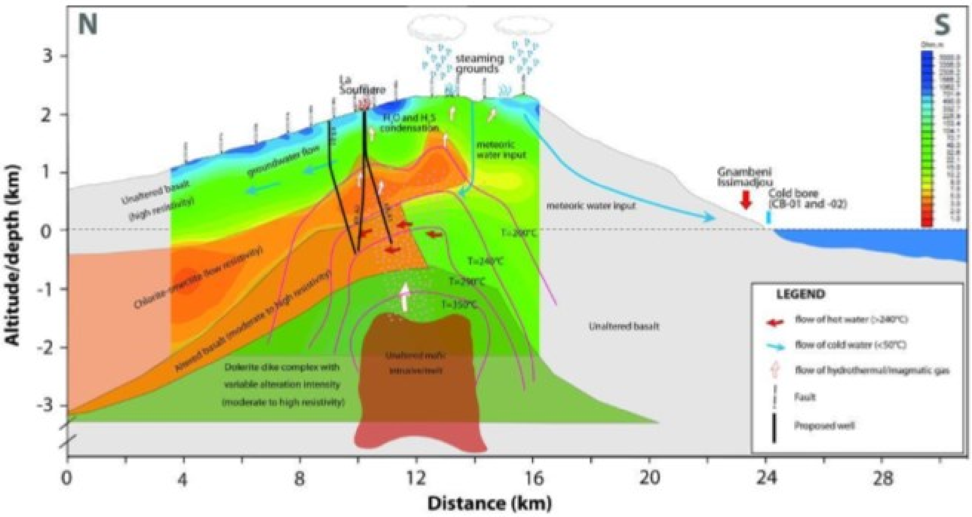

Figure 3: Conceptual model of the geothermal system including proposed geothermal wells (Jacobs, 2015).

3.4 3D MT Model Development to Assess Potential Groundwater Occurrence

3.4.1 Method

An 80 station MT survey of Mt. Karthala was conducted by Jacobs and GNS in July-August 2015. A 3D inversion model of the data was created by CGG. 3D and 1D inversion models of the MT data were used to assess resistivity variations in the upper few hundred metres of the subsurface to see if any layered contrasts exist that may be related to the transition of unsaturated to groundwater-saturated zones. The 3D MT model was interpolated and manipulated in Leapfrog Geo and an approximation of the water table, based on the 500 Ωm isosurface, was manually created.

3.4.2 MT Model Results

The large-scale resistivity signature of the northern flank of Karthala is consistent with that observed at volcanic geothermal systems around the world. Specifically, there are three broad layers:

1) An upper high resistivity layer (>20 Ωm) stretching from the surface to a depth a 600-1000 mVD that likely represents unaltered volcanic rocks;
2) a 1,000-1,500 m-thick low resistivity layer (<2-20 Ωm) that likely represents argillically-altered volcanic rock above a geothermal system (i.e., the clay cap); and
3) a basal high resistivity layer that likely corresponds to propylitically-altered volcanic rock in a geothermal reservoir.

The MT Model Results show that the 500 Ωm isosurface may be a rough approximation of the groundwater level in the survey area. However, there is thus a large degree of uncertainty regarding the quantification of the water table depth by this method.

The depth to this isosurface is greatest in the south, amounting to 500-600 m near the summit of Mt. Karthala (disregarding the area within the summit craters), and becomes more shallow in the lower elevation regions, reaching a minimum depth of 100-200 m in the northern part of the study area.

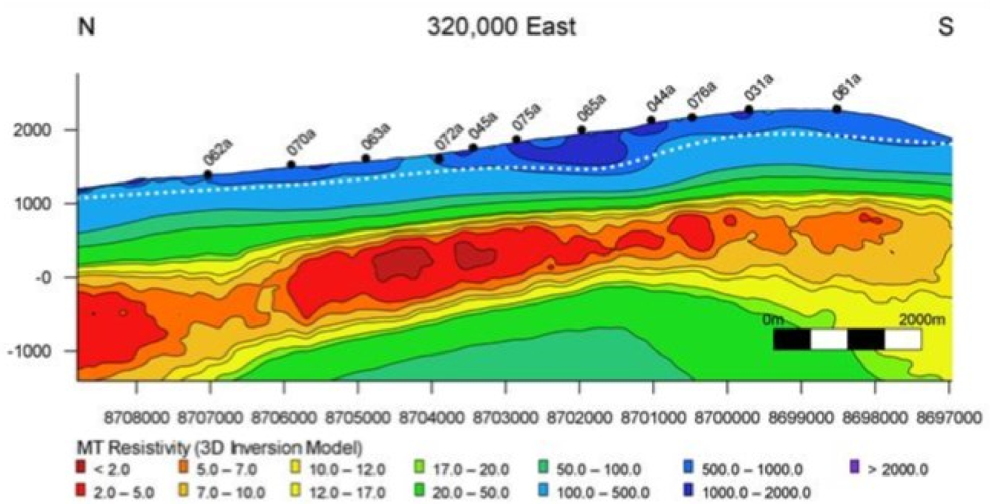

Figure 4: Cross-section through the 3D MT resistivity model along 320,000 mE showing MT station locations and the interpreted depth to the water table (white dotted line – roughly corresponds to the base of the 500 Ωm isosurface) (Jacobs, 2016).

3.5 Surface Water Resources within the Study Area

Studies done by Jacobs in 2016 identified four potential catchments that may be suitable for water abstraction. For the purposes of assessing yields, two catchments were chosen due to their area and proximity to drilling sites (see Table 3). Subsequent simulations on the large catchment (B) were undertaken to determine suitability for water supply.

Table 3: Catchment areas and elevations

Catchment	Area (ha)	Elevation (Weir to Reservoir) (m)
B	405	620
C	341	600

3.5.1 Surface Runoff

Despite the abundance of rainfall on Grande Comore there are limited surface streams due to the high permeability of the volcanic deposits and fractured nature/high transmissivity of the lava flows and volcanic soils (Jacobs, 2016). Total infiltration for Grande Comore was estimated at 95% by UNDTCD (1987) giving an effective runoff rate of 5%.

Given the limited flow or runoff data, an estimate of the amount of runoff generated during a rain event was determined through the development of runoff curves (Figure 5). These represent an approximation of runoff proportions that may drain through a catchment under different rainfall intensities.

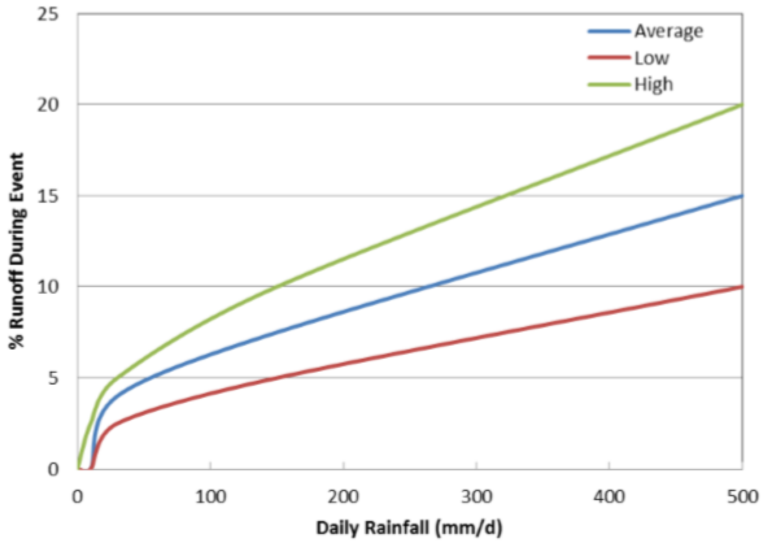

Figure 5: Rainfall runoff curves (Jacobs, 2017).

3.6 Water Supply Modelling (Groundwater and Surface Water)

3.6.1 Modelling Method

Water supply modelling was undertaken using the software GoldSim which is a Monte Carlo capable 1D numerical model that allows for incorporation of uncertainty into simulations.

The approach used in the surface and groundwater modelling was as follows:

- Run a daily model for the wet, dry and average historic annual rainfall time series;
- Simulation duration was 365 days, starting on January 1st for each rainfall time series;
- Abstraction is simulated as either water pumped from a weir or bores, that is then transferred to a staged reservoir (required due to elevation differences);
- Water is pumped through four hypothetical stages to a final main reservoir, which is used to meet the drilling demand;
- Pump rates, bore flows and weir size are optimised through iterations to identify where required demand is met by the modelled abstraction.

The model will provide outputs on a daily time step which includes water levels, instantaneous and cumulative volumes, flow rates and reliability (e.g., days the production reservoir runs dry under each scenario).

3.6.2 Groundwater Supply Modelling Results

The dynamic demand scenario is the most likely representation of abstraction during drilling, as this represents typical real life drilling conditions. The fixed demands (3,000 and 5,000 m3/d) are considered to be worst case scenarios, and could indicate blind drilling at a high rate continuously for 60 days per hole (potentially this could occur with extreme water losses). Under the dynamic demand scenarios (1e and 1f) a bore flow rate of:

- 48.2 L/s will be required for an 8,000 m3 production reservoir; and
- 41.8 L/s will be required for a 16,000 m3 production reservoir.

The worst case scenario would be 1a which will require a bore field flow rate of 57.3 L/s to implement. This scenario requires a higher flow rate than the ones with the dynamic scenario because the reservoir size is smaller (8,000 m3) and considers a high constant demand of 5,000 m3/d.

Table 4: Groundwater bore scenarios (Jacobs 2017)

Scenario	Reservoir Size (m3)	Additional Criteria
1a	8,000	5,000 m3 /d demand for 60 days per hole
1b		3, 000 m3 /d demand for 60 days per hole
1c	16,000	5, 000 m3 /d demand for 60 days per hole
1d		3, 000 m3 /d demand for 60 days per hole
1e	8,000	Dynamic Demand
1f	8,000	Dynamic Demand

Table 5: Groundwater bore flow rate results (Jacobs 2017)

Scenario	Reservoir Size (m3)	Required Bore Field Flow Rate (L/s)
1a	8,000	57,3
1b		34.3
1c	16,000	55,9
1d		32.7
1e	8,000	48.2
1f	8,000	41.8

3.6.2 Surface Water Supply Model Results

The surface water modelling was undertaken on Catchment B, which was chosen due to its closer proximity to the proposed geothermal wells and the larger catchment area. Numerous scenarios were considered for the surface water supply option. This considered variations in weir size, pumping flow rates and demand. See Table 6 for a summary of the scenarios considered.

Table 6: Catchment scenario

Scenario	Reservoir Size (m3)	Pump rate (L/s)	Additional Criteria
2a	N/A	N/A	Catchment B cumulative runoff yield only
2b	16,000	60	5,000 m3/d demand for 60 days per hole, 1,200 m3 weir
2c		120	
2d		60	3,000 m3 /d demand for 60 days per hole, 1,200 m3 weir
2e		120	
2f	16,000		Dynamic Demand , 5,000 m3 weir
2g	8,000		
2h	varies		Dynamic Demand, 5,000 m3 or 20,000 m3weir

Catchment modelling indicates that to meet the dynamic drilling rig demand the primary production reservoir would need to be 85,000–105,000 m^3 (depending on weir volume). The reservoir size may be able to be optimized with higher pumping rates and larger weir volumes. However, given the requirements are for a reservoir of between 8,000–16,000 m3 this water supply option is considered to be unsuitable for meeting the rig demand.

A reservoir volume of 105,000 m^3 would have approximate dimensions of 200 m (L) x 166 m (W) x 3.5 m (H), with 2:1 side slopes. This significant size and the requirement to be lined would result in an exorbitant construction cost and effort that is not supported by a guarantee of supply.

4. COST ESTIMATE FOR EXPLORATION DRILLING

Table 7: Cost estimate for exploration drilling only

Group – Exploration drilling	$US000's
Feasibility Study	600
Infrastructure (for exploration) roading, water supply, wellpad preparation	23,000
Exploration Wells (x3)	26,100
FEED, Contract Prep, PM & Site Supervision	3,400
Total (including 10% estimating margin)	**53,100**
Approved GRMF Oct 2017 (originally $8.2 Dec 15)	10,870
GEF	6,000
Co-funding sought	**36,230**

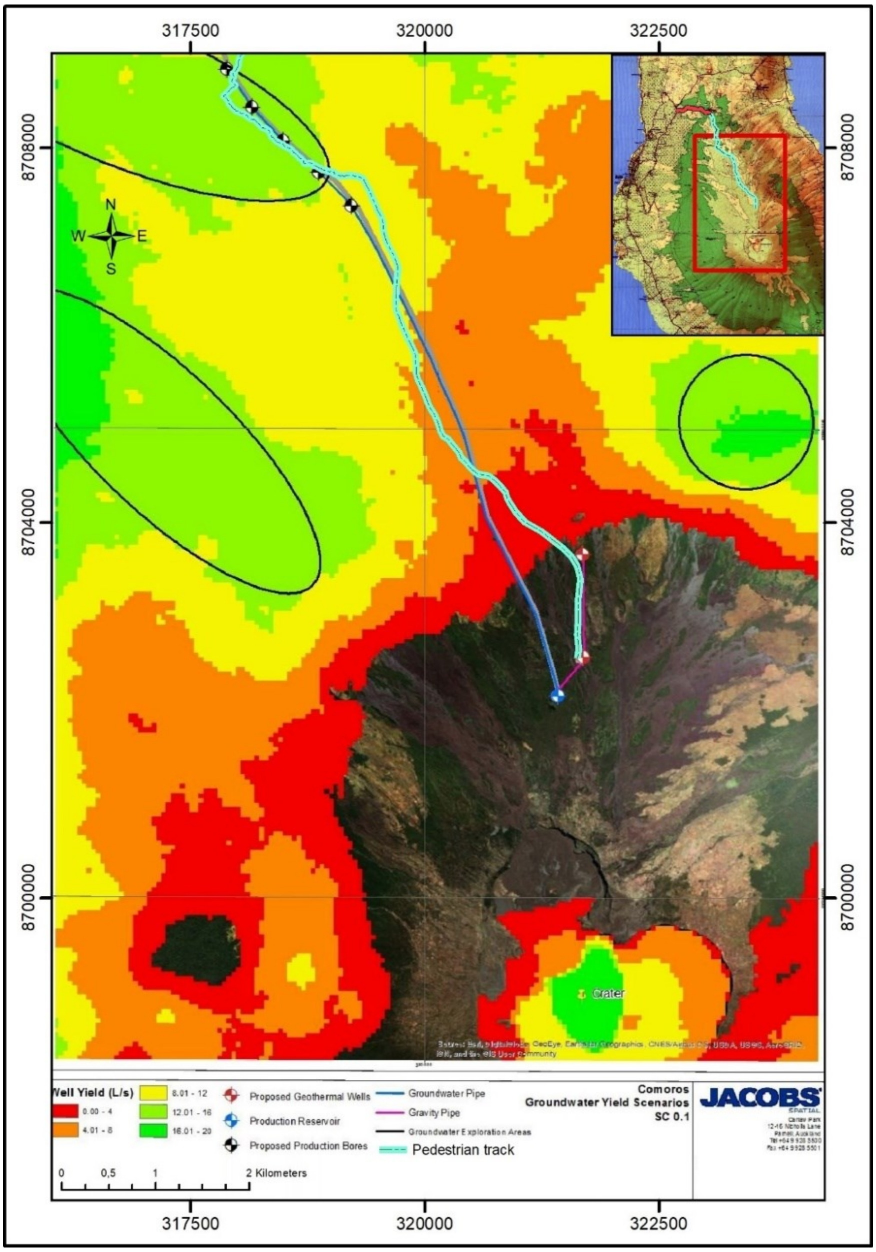

Figure 6: Possible areas for groundwater exploration

CONCLUSION

Based on the information and studies completed to date, the civil development for the exploration drilling operation is feasible but at a cost. Found locally on Grande Comore are the majority of the elements to make the civil development successful, including:

- Moroni Terminal is able to comfortably accommodate the shipping containers
- The existing roadway infrastructure is suitable to handle the loads;
- Trucking companies with trucks & trailers capable of handling the trucking needs;
- Local contractors are well equipped to construct the access road and well pad sites for drilling;
- Collaborative and engaged public officials and stakeholders willing to work with the project team to ensure success.

Water supply utilizing groundwater is the preferred option for exploration drilling as it potentially has the added benefit of supplying communities in the area with a water supply which they otherwise access from bores near Moroni. However, exploratory groundwater bores need to be drilled in the proposed area (figure 6) to confirm the presence and outputs of the shallow aquifers. An ESIA is currently underway which will identify land ownership and usage, impacts of the flora and fauna and social issues that may arise from this project.

The cost estimate for civil works and the preferred water supply option is approximately USD23M (+/- 40%). Even for a relatively small geothermal development the infrastructure requirements are a significant portion of the total exploration costs. This is due to the relatively isolated location and challenging terrain in Grande Comore, a lack of surface water on the island and the significant distances and (most importantly) the very large elevation changes from the water supply points at the coast and nearby Bahani to the drill site.

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