Noise Impact Assessment for the Proposed Menengai Geothermal Power Plant in Kenya

Project done for **Quantum Power East Africa**

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Revision Record

Version	Date	Section(s) Revised	Summary Description of Revision(s)

Glossary and Abbreviations

Airshed	Airshed Planning Professionals (Pty) Ltd
EHS	Environmental, Health, and Safety
EMCR	Environmental Management and Coordination Regulations (Kenya)
IEC	International Electrotechnical Commission
IFC	International Finance Corporation
kVA	kilo volt ampere
kV	kilo volt
L_{Aeq} (T)	The A-weighted equivalent sound pressure level, where T indicates the time over which the noise is averaged (calculated or measured) (L_{Aeq} (T)) (in dBA)
L_{A90}	The A-weighted 90% statistical noise level, i.e. the noise level that is exceeded during 90% of the measurement period. It is a very useful descriptor which provides an indication of what the L_{Aeq} could have been in the absence of noisy single events and is considered representative of background noise levels (L_{A90}) (in dBA)
L_{AFmax}	The A-weighted maximum sound pressure level recorded during the measurement period
L_{AFmin}	The A-weighted minimum sound pressure level recorded during the measurement period
L_P	Sound pressure level (in dB)
L_{PA}	A-weighted sound pressure level (in dBA)
L_{PZ}	Un-weighted sound pressure level (in dB)
L_W	Sound Power Level (in dB)
m	distance in meter
NEMA	National Environment Management Authority (Kenya)
MVA	Mega volt ampere
MW	Mega Watt
QPEA	Quantum Power East Africa
SABS	South African Bureau of Standards
SANS	South African National Standards
SLM	Sound Level Meter
SoW	Scope of Work
V	volts
WHO	World Health Organisation

Executive Summary

Airshed Planning Professionals (Pty) Ltd (Airshed) was commissioned by Quantum Power East Africa (QPEA) to undertake an environmental noise impact assessment for the operational phase of the Proposed Menengai Geothermal Power Plant in Kenya.

The QPEA facility will generate up to 27.7 mega Watt (MW) using a single flash condensing steam turbine and main sources of noise will include the steam turbine, the generator, the droplet separator; the steam strainer, valves (main and stop valves), pumps (incl. oil pumps, vacuum pumps, hotwell pumps and cooling water pumps), ejectors, the main condenser, the cooling towers and transformers. The turbine, generator and some pumps and valves will be enclosed within the turbine hall which will be constructed of structural steel and cladded with galvanized (zinc coated) IBR steel sheets that have a thickness of 0.58 mm and will have a concrete floor. Whereas both the cladding and concrete floor of the turbine hall will absorb some of the sound energy emitted from sources of noise inside the turbine hall, the cladding will also to some extent limit the amount of sound energy emitted through the building's façades.

Two technology options are considered for the release of non-condensable gases (NCG) to the atmosphere. These are to either emit the NCG through a tall stack or to emit it through the cooling towers. Although the release of NCG through a tall stack will add additional sources of noise i.e. fans, valves, pipes etc., these will be immaterial in comparison with other major sources of noise. This assessment did therefore not distinguish between the technologies considered for the release of the NCG.

The QPEA plant will be operated alongside two other independent power producing plants referred to as the Ormat and Sosian Geothermal Power Plants. These were included in the assessment and assumed to be identical in design to the QPEA facility.

From a review of available project information the following tasks were proposed as part of the scope of work:

- A review of the legal requirements and applicable environmental noise guidelines.
- A desktop study of the receiving (baseline) acoustic environment.
- The establishment of a source inventory for proposed operational phase operations.
- Noise propagation modelling to determine environmental noise levels.
- The screening of simulated noise levels against environmental noise criteria.
- The development of a noise management plan including the identification of suitable mitigation measures and monitoring requirements.
- A specialist noise impact assessment report.

The Kenyan National Environmental Management Authority restricts outdoor noise in residential areas to 50 dBA during the day and 35 dBA during the night whereas the IFC recommends 55 dBA and 45 dBA as noise level guidelines. Kenyan limits are therefore more stringent. The IFC also recommends that an industrial development not result in an increase of more than 3 dBA at noise sensitive receptors (NSRs) since it is the level at which a person with average hearing acuity will be able to detect a change.

The baseline acoustic environment was described in terms of the location of NSRs in relation to the proposed development, the ability of the environment to attenuate noise over long distances and existing or pre-development noise levels. The following was found:

- NSRs include single homesteads, villages and community locations. The closest of these lie with 3.5 to 4 km south west and north-west of the proposed QPEA facility.
- Atmospheric conditions are more conducive to noise attenuation during the day.
- The wind field is characterised by winds from the south-south-east and north-north-west. Noise impacts will be more notable in these downwind directions.
- Noise level measurements were limited. After careful consideration and analysis of available data representative but conservative baseline day- and night-time noise levels within the Menengai crater of 55.2 and 45.2 dBA were determined. These levels are conservative in the sense that these values are on the lower end of what was measured which will theoretically result in noise from the proposed project to be more notable. These levels are however already in exceedance of both the Kenyan limits and IFC guidelines.

Sound power levels for main equipment were determined from supplier specifications and theoretical calculations. The effective sound power level of the turbine hall was also estimated by taking into account the building size, sound absorption by cladding and floor as well as transmission losses through the galvanised steel sheet cladding. The source inventory, local meteorological conditions and information on local land use were used to populate the noise propagation model (Concawe). Noise levels were calculated over an area of 5 km east-west by 5 km north-south at intervals of 50 m. The following was found:

- Noise impact will be most significant at night when baseline noise levels are lower and assessment criteria more stringent.
- With all three facilities operating simultaneously the overall maximum increase in noise level over the baseline will reduce to less than 3 dBA at around 1.72 km from the boundary of operations.
- Since the closest NSRs are situated at least 3 km away from these sites it is unlikely a change in day or night time noise levels will be detected at these locations.
- SANS 10103 (2008) indicates that at an increase of between 0 and 5 dBA, sporadic complaints with little or no community action may be expected.
- The relatively small impact area is the combined result of the baseline noise levels (already in exceedance of assessment criteria), the design specifications of the facilities (i.e. galvanised steel sheet cladding of building that contains major noise sources), and the absence of permanent NSRs within 2 km radius from site.

It was concluded that, provided the management plan recommended in this report is adopted, NSR's will not be affected negatively or find noise from the facility annoying. The cladding of the turbine hall with galvanised steel sheeting is considered sufficient from an environmental noise perspective i.e. impacts at NSRs.

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1 INTRODUCTION

Airshed Planning Professionals (Pty) Ltd (Airshed) was commissioned by Quantum Power East Africa (QPEA) to undertake an environmental noise impact assessment for the operational phase of the Proposed Menengai Geothermal Power Plant in Kenya. A description of proposed activities from an environmental noise perspective and tasks included in the Scope of Work (SoW) is given below.

1.1 Description of Proposed Activities from a Noise Perspective

The facility proposed for construction by QPEA will generate a maximum of 37.7 mega Watt (MW) using a single flash condensing steam turbine. The proposed layout of plant is shown in Figure 1. During its operation noise will be generated by a number of elements at the plant. The main sources of noise will include:

- The steam turbine;
- The generator;
- The droplet separator;
- The steam strainer;
- Valves (main and stop valves);
- Pumps (incl. oil pumps, vacuum pumps, hotwell pumps and cooling water pumps)
- Ejectors;
- The main condenser;
- The cooling towers; and
- Transformers.

The turbine, generator and some pumps and valves will be enclosed within the turbine hall which will be constructed of structural steel and cladded with galvanized (zinc coated) IBR steel sheets that have a thickness of 0.58 mm and will have a concrete floor. Whereas both the cladding and concrete floor of the turbine hall will absorb some of the sound energy emitted from sources of noise inside the turbine hall, the cladding will also to some extent limit the amount of sound energy emitted through the building's façades. The need for the installation of additional absorption or insulation materials within the turbine hall will be determined as part of this investigation.

Two technology options are considered for the release of non-condensable gases (NCG) to the atmosphere. These are to either emit the NCG through a tall stack or to emit it through the cooling towers. The preferred technology will most likely be determined by the air quality impact assessment for the plant since it is dependent on the effective dispersion of harmful and odorous hydrogen sulphide contained in the NCG. Although the release of NCG through a tall stack will add additional sources of noise i.e. fans, valves, pipes etc., these will be immaterial in comparison with other major sources of noise (the reader is referred to Section 1.3.3 for some background to the addition of noise levels). This assessment does therefore not distinguish between the technologies considered for the release of the NCG.

Although very detailed design information was available for the operational phase of the plant, the construction and decommissioning phases were less well defined. Construction related activities that will impact on environmental noise levels typically include bulk earthworks, metal works, concrete works and electrical works associated with the establishment of production wells, plant infrastructure, office buildings and support infrastructure.

Decommissioning whole geothermal developments is a rare operation as generally, if the resource conditions are still favourable, equipment can be refurbished or replaced. Power plants can undergo refurbishment at the end of their design life to upgrade and repair equipment to enable operation and generation to continue.

The Proposed Menengai Geothermal Power Plant is one of three such proposed Independent Power Producer (IPP) facilities. The location of two other facilities, referred to as the Ormat and Sosian Geothermal Power Plants, are shown in Figure 2. The cumulative impact of all three facilities on environmental noise levels was raised as a concern and therefore included in the assessment.

1.2 Scope of Work

Given the above, the following tasks were included in the SoW:

1. A review of technical project information.
2. A review of the legal requirements and applicable environmental noise guidelines.
3. A desktop study of the receiving (baseline) acoustic environment, including:
    a. The identification of noise sensitive receptors (NSRs) from available maps;
    b. A study of environmental noise attenuation potential by referring to available weather records, land use and topography data sources; and
    c. The analysis of sampled environmental noise levels to determine representative baseline (pre-development) noise levels.
4. The establishment of a source inventory for proposed operational phase operations.
5. Noise propagation modelling to determine environmental noise levels.
6. The screening of simulated noise levels against environmental noise criteria.
7. The development of a noise management plan including the identification of suitable mitigation measures and monitoring requirements.
8. A specialist noise impact assessment report.

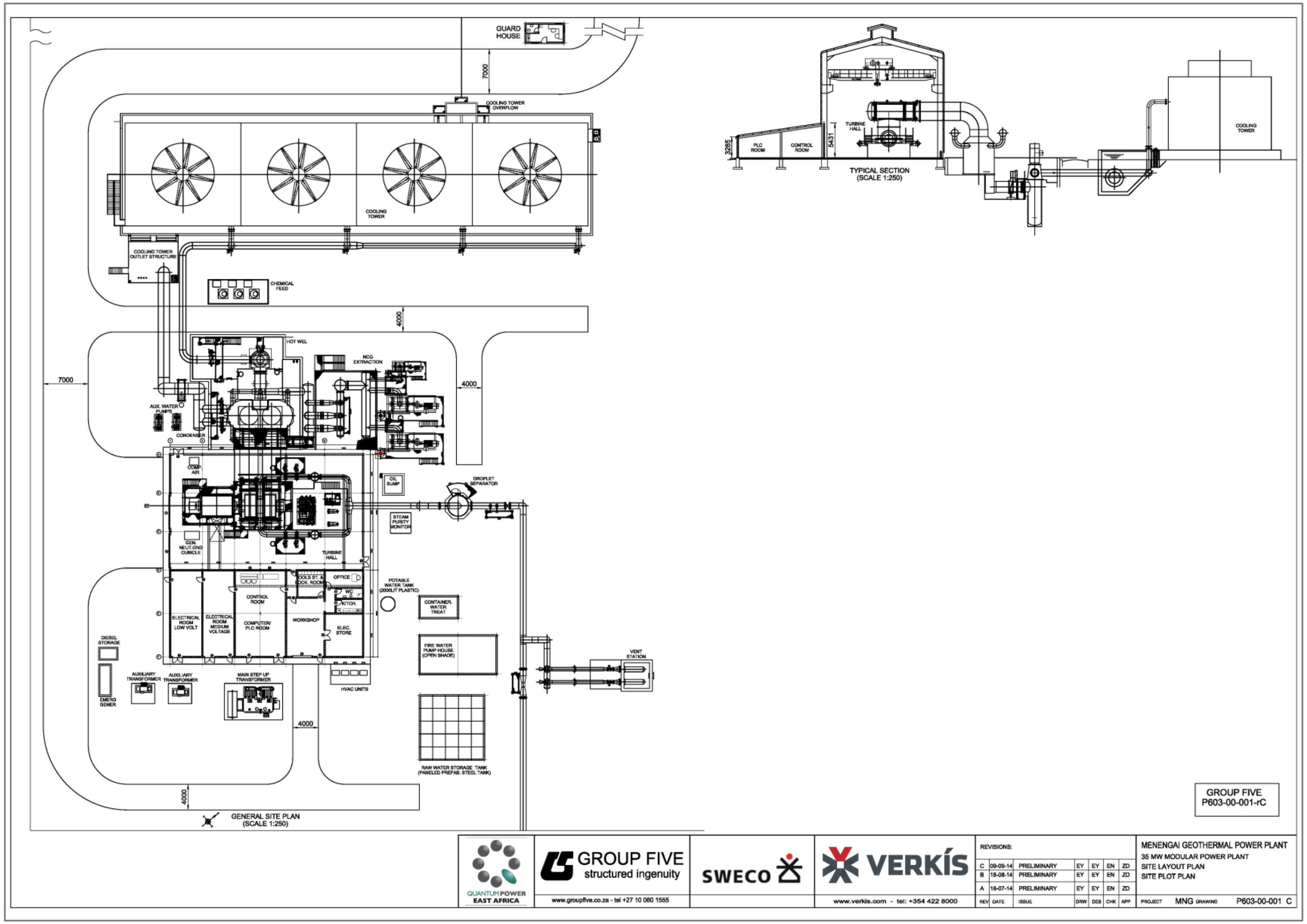


Figure 1: Proposed layout of the Menengai Geothermal Power Plant (layout provided by QPEA)

Figure 2: The Menengai Geothermal Field with the locations of the proposed QPEA (Quantum), Ormat and Sosian geothermal power plants (map provided by QPEA)

1.3 Background to Environmental Noise and the Assessment Thereof

Before more details regarding the approach and methodology adopted in the assessment is given, the reader is provided with some background, definitions and conventions used in the measurement, calculation and assessment of environmental noise.

Noise is generally defined as unwanted sound transmitted through a compressible medium such as air. Sound in turn, is defined as any pressure variation that the ear can detect. Human response to noise is complex and highly variable as it is subjective rather than objective.

Noise is reported in decibels (dB). “dB” is the descriptor that is used to indicate 10 times a logarithmic ratio of quantities that have the same units, in this case sound pressure. The relationship between sound pressure and sound pressure level is illustrated in Equation 1.

$$L_p = 20 \cdot \log_{10}\left(\frac{p}{p_{ref}}\right)$$

Equation 1

Where:

L_p *is the sound pressure level in dB;*
p *is the actual sound pressure in Pa; and*
p_{ref} *is the reference sound pressure (p_{ref} in air is 20 µPa)*

1.3.1 Perception of Sound

Sound has already been defined as any pressure variation that can be detected by the human ear. The number of pressure variations per second is referred to as the frequency of sound and is measured in hertz (Hz). The hearing of a young, healthy person ranges between 20 Hz and 20 000 Hz.

In terms of L_P, audible sound ranges from the threshold of hearing at 0 dB to the pain threshold of 130 dB and above. Even though an increase in sound pressure level of 6 dB represents a doubling in sound pressure, an increase of 8 to 10 dB is required before the sound subjectively appears to be significantly louder. Similarly, the smallest perceptible change is about 1 dB (Brüel & Kjær Sound & Vibration Measurement A/S, 2000).

1.3.2 Frequency Weighting

Since human hearing is not equally sensitive to all frequencies, a ‘filter’ has been developed to simulate human hearing. The ‘A-weighting’ filter simulates the human hearing characteristic, which is less sensitive to sounds at low frequencies than at high frequencies (Figure 3). “dBA” is the descriptor that is used to indicate 10 times a logarithmic ratio of quantities, that have the same units (in this case sound pressure) that has been A-weighted.

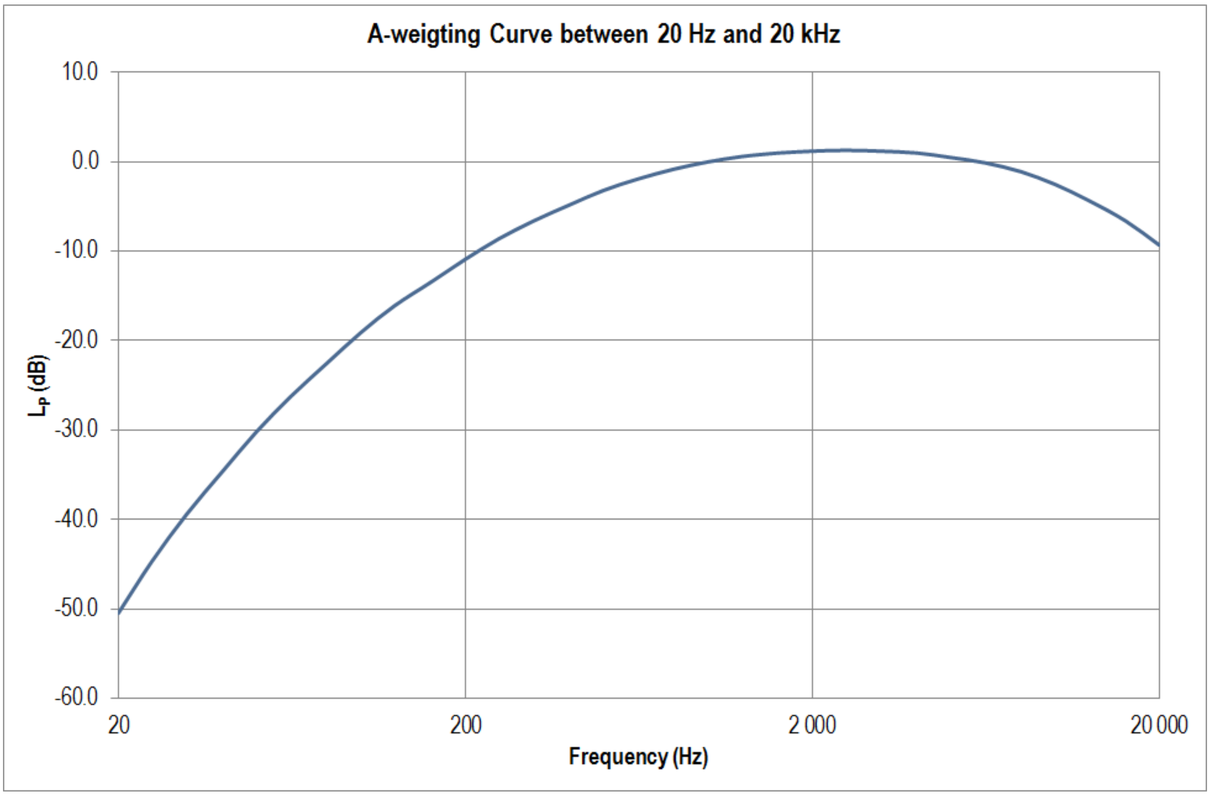


Figure 3: A-weighting curve

1.3.3 Adding Sound Pressure Levels

Since sound pressure levels are logarithmic values, the sound pressure levels as a result of two or more sources cannot just simply be added together. To obtain the combined sound pressure level of a combination of sources such as those at an industrial plant, individual sound pressure levels must be converted to their linear values and added using Equation 2.

$$L_{p\_combined} = 10 \cdot \log\left(10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{p2}}{10}} + 10^{\frac{L_{p3}}{10}} + \cdots 10^{\frac{L_{pi}}{10}}\right)$$

Equation 2

This implies that if the difference between the sound pressure levels of two sources is nil the combined sound pressure level is 3 dB more than the sound pressure level of one source alone. Similarly, if the difference between the sound pressure levels of two sources is more than 10 dB, the contribution of the quietest source can be disregarded (Brüel & Kjær Sound & Vibration Measurement A/S, 2000).

1.3.4 Environmental Noise Propagation

Many factors affect the propagation of noise from source to receiver. The most important of these are:

- The type of source and its sound power (L_W);
- The distance between the source and the receiver;
- Atmospheric conditions (wind speed and direction, temperature and temperature gradient, humidity etc.);
- Obstacles such as barriers or buildings between the source and receiver;

- Ground absorption; and
- Reflections

To arrive at a representative result from either measurement or calculation, all these factors must be taken into account (Brüel & Kjær Sound & Vibration Measurement A/S, 2000).

1.3.5 Environmental Noise Indices

In assessing environmental noise either by measurement or calculation, reference is generally made to the following indices:

- **L_{Aeq} (T)** – The A-weighted equivalent sound pressure level, where T indicates the time over which the noise is averaged (calculated or measured). The International Finance Corporation (IFC) provides guidance with respect to L_{Aeq} (1 hour), the A-weighted equivalent sound pressure level, averaged over 1 hour.
- **L_{A90}** – The A-weighted 90% statistical noise level, i.e. the noise level that is exceeded during 90% of the measurement period. It is a very useful descriptor which provides an indication of what the L_{Aeq} could have been in the absence of noisy single events and is considered representative of background noise levels.
- **L_{AFmax}** – The maximum A-weighted noise level measured with the fast time weighting. It's the highest level of noise that occurred during a sampling period.
- **L_{AFmin}** – The minimum A-weighted noise level measured with the fast time weighting. It's the lowest level of noise that occurred during a sampling period.

1.4 Approach and Methodology

The assessment included a study of the legal requirements pertaining to noise impacts, a study of the physical environment of the area surrounding the project and the analyses of existing noise levels in the area. The impact assessment focused on the estimation of L_W's (noise 'emissions') and L_P's (noise impacts) associated with the operational phase of the facility. The findings of the assessment components informed recommendations of management measures, including mitigation and monitoring. Individual aspects of the noise impact assessment methodology are discussed in more detail below.

1.4.1 Information Review

An information requirements list was submitted to QPEA at the onset of the study. QPEA supplied, for inclusion in the assessment, the following information:

- Georeferenced maps and a site layout;
- A detailed process description;
- Source noise levels for most major plant equipment;
- Information on building construction materials; and
- Sampled baseline environmental noise levels.

Gaps or limitations in the information supplied were identified. These were addressed by making suitable technical assumptions which were approved by QPEA.

1.4.2 Review of Assessment Criteria

In Kenya, the National Environment Management Authority (NEMA) regulates Noise and Excessive Vibration Pollution under the Environmental Management and Coordination Regulations (EMCR) (NEMA, 2009). These regulations as well as guidance provided by the IFC were considered in the assessment.

1.4.3 Study of the Receiving Environment

Noise sensitive receptors generally include private residences, community buildings such as schools, hospitals and any publically accessible areas outside the industrial facility's property. QPEA provided the coordinates of homesteads, villages and areas to be considered.

The ability of the environment to attenuate noise as it travels through the air was studied by considering local meteorology, land use and terrain. Atmospheric attenuation potential was described based on modelled MM5 weather data obtained for 2011 to 2014 for the air quality impact assessment. Readily available terrain and land cover data was obtained from the Atmospheric Studies Group (ASG) via the United States Geological Survey (USGS) web site. Use will be made of Shuttle Radar Topography Mission (STRM) (90 m, 3 arc-sec) data and Global Land Cover Characterisation (GLCC) data for Africa.

The extent of noise impacts as a result of an intruding industrial noise depends largely on existing noise levels in the project area. Higher ambient noise levels will result in less noticeable noise impacts and a smaller impact area. The opposite also holds true. Increases in noise will be more noticeable in areas with low ambient noise levels. QPEA supplied available ambient noise measurement data from which baseline noise levels for use in the assessment of cumulative impacts were estimated.

1.4.4 Source Inventory

The source noise inventory was informed by equipment specific L_W data from suppliers and L_W predictive equations. Some sources will be contained within the turbine hall. The effective L_W of these sources combined when emitted through the turbine hall walls (façades) was also estimated.

1.4.5 Noise Propagation Modelling

The propagation of noise from proposed activities was calculated according *to 'The Calculation of Sound Propagation by the Concawe method'* (SANS 10357, 2004). The Concawe method makes use of the International Organisation for Standardization's (ISO) air absorption parameters and equations for noise attenuation as well as the factors for barriers and ground effects. In addition to the ISO method, the Concawe method facilitates the calculation of sound propagation under a variety of meteorological conditions. Meteorological data obtained from the MM5 data set used in the air quality impact assessment were applied in calculations.

If the dimensions of a noise source are small compared with the distance to the listener, it is called a point source. All sources at noise at the proposed plant were quantified as point sources. The sound energy from a point source spreads out spherically, so that the sound pressure level is the same for all points at the same distance from the source, and decreases by 6 dB per doubling of distance. This holds true until ground and air attenuation noticeably affect the level. The impact of an intruding industrial noise on the environment will therefore rarely extend over more than 5 km from the source and is therefore always considered "local" in extent.

The propagation of noise was calculated over an area of 5 km east-west by 5 km north-south with the proposed Quantum plant located centrally. The area was divided into a grid matrix with a 50 m resolution. The model calculates L_P's at each grid receptor point at a height of 1.5 m above ground level.

1.4.6 Presentation of Results

Noise impacts were calculated in terms of:

- Total day- and night time noise levels as a result of:
    - The proposed QPEA plant in addition to the baseline; and
    - The QPEA, Ormat and Sosian geothermal power plants in addition to the baseline.
- The effective increase ambient day and night-time noise levels over the baseline as a result of:
    - The proposed QPEA plant; and
    - The QPEA, Ormat and Sosian geothermal power plants.

Impacts were assessed according to guidelines published by the Kenyan NEMA and IFC. To assess annoyance at nearby places of residence, reference was made to guidelines published in SANS 10103 (2008).

1.4.7 The Development of a Noise Management Plan

The findings of the noise specialist study informed the Noise Management Plan (NMP) which will includes:

- The setting of management objectives;
- The ranking of sources of noise;
- Source specific management and mitigation measures;
- A monitoring plan; and
- Recommendations of record keeping, environmental reporting and community liaison.

2 Legal Requirements and Noise Level Guidelines

2.1 Kenyan Noise Pollution Control Regulations

In Kenya, the NEMA regulates Noise and Excessive Vibration Pollution under the EMCR (NEMA, 2009). Schedule 1 of the regulation gives maximum permissible noise levels for different zones, for construction sites and for mines and quarries. Of specific interest in this assessment are the levels considered acceptable by the NEMA for outdoor noise within residential areas. These are given in Table 1.

Table 1: Kenyan maximum permissible noise levels for residential areas (outdoors)

Zone	Sound Level Limit (dBA)		Noise Rating Level[a]	
	Day-time[a] L_{Aeq} (14 hours)	Night-time[b] L_{Aeq} (10 hours)	Day-time[a] (14 hours)	Night-time[b] (10 hours)
Residential (outdoor)	50	35	40	25

Notes:

(a) Day-time is from 06:01 to 20:00

(b) Night-time is from 20:01 to 06:00

(c) No definition of noise rating level is provided in the regulation

Should a facility emit noise level to such an extent that the above limits are exceeded, and application to emit those noise levels has to be submitted to NEMA.

2.2 IFC Guidelines on Environmental Noise

The IFC General Environmental Health and Safety Guidelines on noise address impacts of noise beyond the property boundary of the facility under consideration and provides noise level guidelines.

The IFC states that noise impacts **should not exceed the levels presented in Table 2**, or result in a maximum **increase above background levels of 3 dBA** at the nearest receptor location off-site (IFC, 2007). For a person with average hearing acuity an increase of less than 3 dBA in the general ambient noise level is not detectable. Δ = 3 dBA is, therefore, a useful significance indicator for a noise impact.

Table 2: IFC noise level guidelines

Noise Level Guidelines (IFC, 2007)		
Area	One Hour L_{Aeq} (dBA) 07:00 to 22:00	One Hour L_{Aeq} (dBA) 22:00 to 07:00
Industrial receptors	70	70
Residential, institutional and educational receptors	55	45

2.3 SANS 10103

SANS 10103 (2008) successfully addresses the manner in which environmental noise is to be assessed in South Africa, and is fully aligned with the World health Organisation (WHO) guidelines of 1999. The values given in Table 3 are typical rating

levels that should not be exceeded outdoors in the different districts likely to occur in the study area. Outdoor ambient noise exceeding these levels will be considered annoying to the community.

Table 3: SANS 10103 (2008) typical rating levels for outdoor noise

Type of district	Equivalent Continuous Rating Level ($L_{Req,T}$) for Outdoor Noise SANS 10103 (2008)[6]		
	Day/night $L_{R,dn}$[(c)] (dBA)	Day-time $L_{Req,d}$[(a)] (dBA)	Night-time $L_{Req,n}$[(b)] (dBA)
Rural districts	45	45	35
Suburban districts with little road traffic	50	50	40
Urban districts	55	55	45
Urban districts with one or more of the following; business premises; and main roads	60	60	50
Central business districts	65	65	55
Industrial districts	70	70	60

Notes

(a) $L_{Req,d}$ =The L_{Aeq} rated for impulsive sound and tonality in accordance with SANS 10103 for the day-time period, i.e. from 06:00 to 22:00.

(b) $L_{Req,n}$ =The L_{Aeq} rated for impulsive sound and tonality in accordance with SANS 10103 for the night-time period, i.e. from 22:00 to 06:00.

(c) $L_{R,dn}$ = The L_{Aeq} rated for impulsive sound and tonality in accordance with SANS 10103 for the period of a day and night, i.e. 24 hours, and wherein the $L_{Req,n}$ has been weighted with 10dB in order to account for the additional disturbance caused by noise during the night.

SANS 10103 (2008) also provides a useful guideline for estimating community response to an increase in the general ambient noise level caused by intruding noise. If Δ is the increase in noise level, the following criteria are of relevance:

- $\Delta \leq 0$ dB: There will be no community reaction;
- 0 dB < $\Delta \leq$ 10 dB: There will be 'little' reaction with 'sporadic complaints';
- 5 dB < $\Delta \leq$ 15 dB: There will be a 'medium' reaction with 'widespread complaints'. Δ = 10 dB is subjectively perceived as a doubling in the loudness of the noise;
- 10 dB < $\Delta \leq$ 20 dB: There will be a 'strong' reaction with 'threats of community action'; and
- 15 dB < Δ: There will be a 'very strong' reaction with 'vigorous community action'.

The categories of community response overlap because the response of a community does not occur as a stepwise function, but rather as a gradual change.

3 DESCRIPTION OF THE RECEIVING ENVIRONMENT

This chapter provides details of the receiving acoustic environment in terms of:

- Local NSRs;
- The local environmental noise propagation and attenuation potential; and
- Locally sampled baseline noise levels.

3.1 Noise Sensitive Receptors

A map of likely NSRs is included in Figure 4. These include single homesteads, villages, large towns as well as community locations. The closest NSRs are situated approximately 3.5 km north-west of the facility on the crater rim at Marigo. Within the crater itself the individual homestead and structures to the south-west (approximately 3.7 km from the facility) are the closest.

3.2 Environmental Noise Propagation and Attenuation potential

3.2.1 Atmospheric Absorption and Meteorology

Atmospheric absorption and meteorological conditions have already been mentioned with regards to its role in the propagation on noise from a source to receiver (Section 1.3.4). The main meteorological parameters affecting the propagation of noise include wind speed, wind direction and temperature. These along with other parameters such as relative humidity, air pressure, solar radiation and cloud cover affect the stability of the atmosphere and the ability of the atmosphere to absorb sound energy. Average day-and night time wind speed, wind direction, temperature, relative humidity, pressure and solar radiation used as input to the selected noise propagation model are provided in Table 4. Modelled MM5 data (2011 to 2013) for an on-site location was referred to.

It is well known that wind speed increases with altitude. This results in the 'bending' of the path of sound to 'focus' it on the downwind side and creating a 'shadow' on the upwind side of the source. Depending on the wind speed, the downwind level may increase by a few dB but the upwind level can drop by more than 20 dB (Brüel & Kjær Sound & Vibration Measurement A/S, 2000). It should be noted that at wind speeds of more than 5 m/s ambient noise levels are mostly dominated by wind generated noise. The on-site diurnal wind field is presented in Figure 5. Wind roses represent wind frequencies for the 16 cardinal wind directions. Frequencies are indicated by the length of the shaft when compared to the circles drawn to represent a frequency of occurrence. Wind speed classes are assigned to illustrate the frequencies with high and low winds occurring for each wind vector. The frequencies of calms, defined as periods for which wind speeds are below 1 m/s, are also indicated.

On average, during the day, noise impacts are expected to be most notable to the north-north-west and south-south east. During the night it is expected to be most significant to the north-north-west of proposed operations.

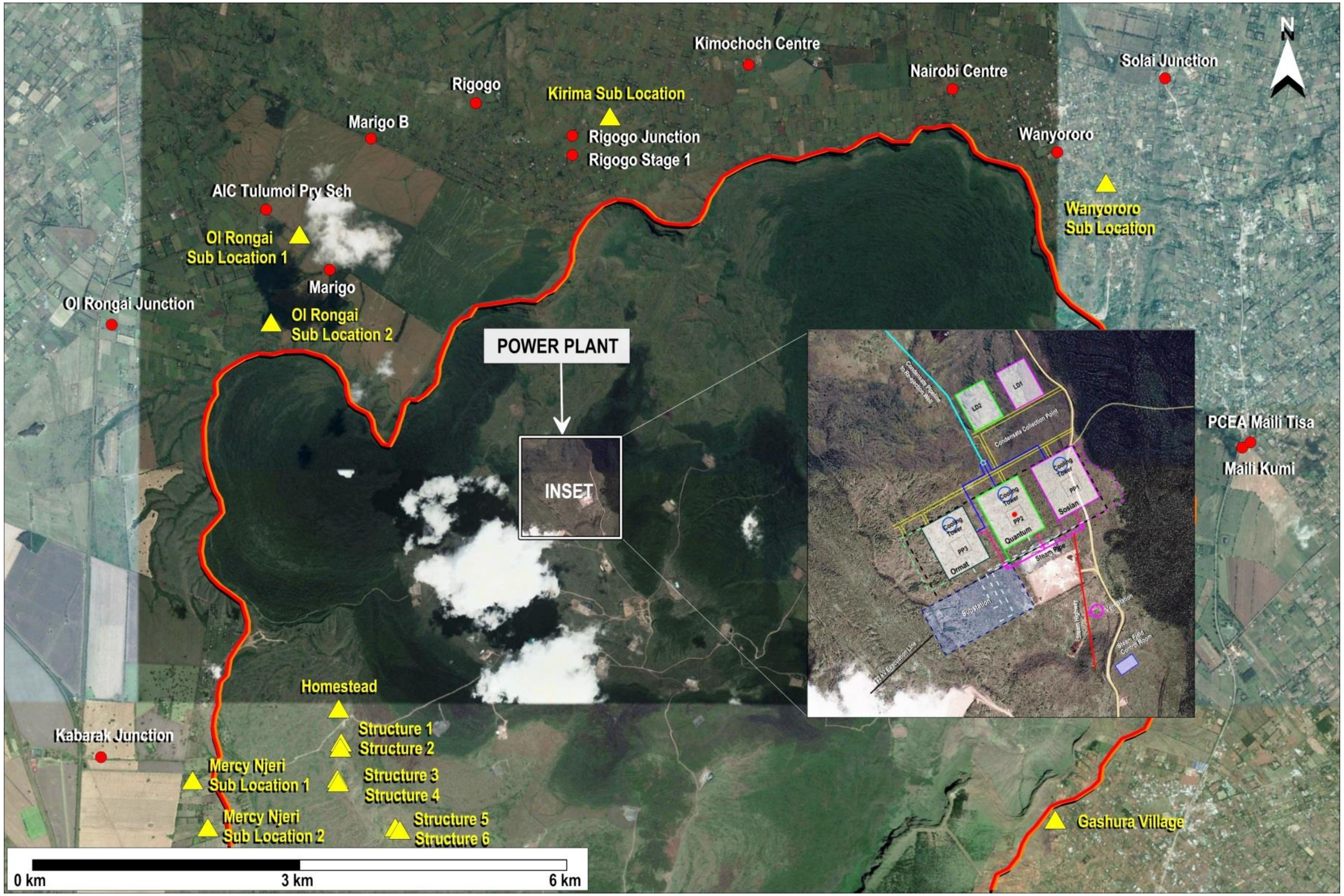
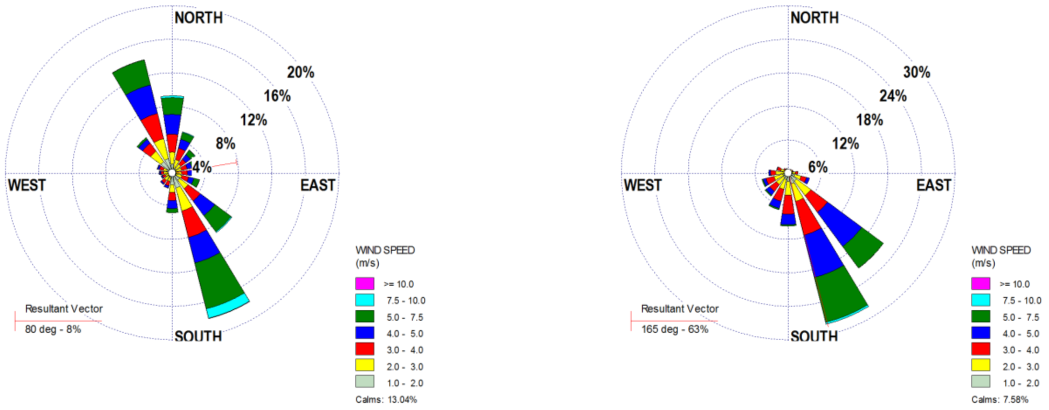


Figure 4: Location of potential NSR's



(a) Day-time wind field **(b) Night-time wind field**

Figure 5: Wind roses

Temperature gradients in the atmosphere create effects that are uniform in all directions from a source. On a sunny day with no wind, temperature decreases with altitude and creates a 'shadowing' effect for sounds. On a clear night, temperatures may increase with altitude thereby 'focusing' sound on the ground surface. Noise impacts are therefore generally more notable during the night.

Table 4: Average diurnal meteorological parameters

Parameter	Average Diurnal Meteorological Parameters (MM5 data 2011 to 2013)	
	Day-time	Night-time
Temperature	19/5 °C	14.6 °C
Relative Humidity	57.7%	79.15%
Wind Speed	3.3 m/s	3.3 m/s
Wind Direction (from)	SSE	SSE
Air Pressure	80.9 kPa	81.0 kPa
Solar Radiation	300 W/m^2	not applicable
Cloud cover (octas)	3	4

3.2.2 Terrain, Ground Absorption and Reflection

Noise reduction caused by a barrier (i.e. natural terrain, installed acoustic barrier, building) feature depends on two factors namely the path difference of the sound wave as it travels over the barrier compared with direct transmission to the receiver and the frequency content of the noise (Brüel & Kjær Sound & Vibration Measurement A/S, 2000). There are however no features with the local study area that may act as acoustic barriers between the proposed site and local NSRs. The crater edge is too far away from the plant and NSRs to result in a notable change in noise levels.

Sound reflected by the ground interferes with the directly propagated sound. The effect of the ground is different for acoustically hard (e.g., concrete or water), soft (e.g., grass, trees or vegetation) and mixed surfaces. Ground attenuation is often calculated in frequency bands to take into account the frequency content of the noise source and the type of ground between the source and the receiver (Brüel & Kjær Sound & Vibration Measurement A/S, 2000). Ground cover includes

vegetation, residential and farming areas and is considered acoustically ‘mixed’. 75% of the 5 by 5 km study area/ modelling domain was conservatively assumed to be acoustically ‘soft’.

3.2.3 Baseline Noise Levels

QPEA supplied, for use in the determination of baseline/background noise levels, two sets of measurement data (see Appendix A) collected by a third party within and around the Menengai crater. These data sets included:

- Average day-time noise levels at several locations within the crater near drilling operations/well areas as reported by Muse in 2013. The sampling period or acoustic parameter sampled is not clearly indicated and values were assumed to be L_{Aeq} values; and
- Minimum and maximum night-time noise levels at NSRs (shown by the red dots in Figure 4). Since it was not specified these values were assumed to be the L_{AFmax} and L_{AFmin} values of the samples taken over a period of 10 months.

It is clear the data sets area limited in the following ways:

- Time averaging periods are not indicated;
- Day and night-time measurements were not conducted at the same locations;
- Day-time measurements were limited to the Menengai crater where noise levels were affected by drilling operations;
- Night-time measurements were all conducted outside the Menengai crater within community areas.

Since the night-time measurement data set is more detailed, providing minimum and maximum sampled noise levels over approximately 40 days at locations outside Menengai, it used it as a starting point for determining representative baseline/background noise levels from which cumulative impacts could be determined. Herewith the approach:

- Night time samples were all taken within community locations and will therefore most likely be higher than what is found within Menengai.
- **Median of minimum** values sampled at night time sampling site was determined.
- The lowest of these is medians were found to be 45.2 dBA and is considered representative of night-time levels within the crater.
- The difference in day and night time levels in areas where there is human activity is usually about 10 dBA (SANS 10103, 2008).
- The equivalent day-time noise level within Menengai would, by applying the above, be 55.2 dBA.
- The estimated 55.2 dBA baseline day-time noise level corresponds to lower end of reported average by Muse (2013).
- For estimating cumulative impacts within Menengai crater, the following conservative representative background noise levels were therefore used:
    - 45.2 dBA for the night; and
    - 55.2 dBA for the day.

It is important to note that day and night time baseline noise levels are in exceedance of Kenyan and IFC noise levels guidelines for residential areas.

4 Impact Assessment

The noise source inventory, noise propagation modelling and results for the operational phase are discussed in Section 4.1 and Section 4.2.

4.1 Noise Sources and Sound Power Levels

QPEA provided the following supplier technical information on main sources of noise which are summarised in Table 5:

- Octave band L_W's for the **cooling towers** and **droplet separator**;
- Octave band L_P's 1 meter from the **turbine**, **generator**, **steam strainer**, **valves**, **pumps**, **ejectors** and **main condenser**;
- Source locations and quantities.

Table 5: Source information supplied by QPEA

Equipment Name	L_W or L_P	L_W or L_P in dBA									Area (m^2) or Point	Distance from Source of L_P (meters)	Quantity
		63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	Tot.			
Droplet Separator	L_W	46	42	44	50	62	62	57	55	66	Point	n/a	1
Steam Strainer	L_P	55	60	64	67	68	66	57	53	73	Point	1	2
Main Stop Valve	L_P	49	85	75	72	76	73	72	65	88	Point	1	2
Main Control Valve	L_P	50	84	68	72	76	73	71	62	88	Point	1	2
Steam Turbine	L_P	70	77	83	84	89	84	78	73	92	104	2.75[(a)]	1
Main Oil Pump	L_P	50	65	72	75	74	73	71	65	81	Point	1	2
Main Oil Tank Vapour Extractor	L_P	20	39	51	57	59	58	54	48	64	Point	1	1
Control Oil Pump	L_P	53	55	60	78	75	75	73	64	80	Point	1	2
Control Oil Radiator	L_P	31	50	62	68	70	69	65	60	75	Point	1	1
Generator	L_P	71	89	78	80	82	79	70	58	91	89	3.25[(a)]	1
Main Condenser	L_P	52	62	74	82	86	85	81	75	90	140	3.3[(a)]	1
Ejector	L_P	61	71	86	100	107	106	104	102	112	Point	1	3
Inter Condenser	L_P	53	63	79	92	99	98	96	94	104	Point	1	1
Vacuum Pump	L_P	56	73	80	86	86	83	79	65	91	Point	1	4
Hotwell Pump	L_P	30	66	81	80	79	73	64	52	85	Point	1	2
Auxiliary Cooling Water Pump	L_P	76	78	79	76	74	73	69	64	80	Point	1	2
Cooling Tower	L_W	104	101	98.8	98.0	99.7	99.1	98.9	101	106	Point	n/a	4

For use in the noise propagation simulations representative L_W's for these sources were determined from Equation 3 for the spherical diversion of noise from a point source:

$$L_P = L_W + 10 \cdot \log_{10} r + 8\ dB$$

Equation 3

Where L_p is the sound pressure level in dB at distance **r** from the sources and L_W is the actual sound power level of the source under consideration.

L_W's from the 11 kV to 132 kV generator step up transformer (50 MVA), 11 kV to 0.68 kV station service transformer (4 MVA) and 11 kV to 11 kVA to 425 V auxiliary transformer (350 kVA) were estimated with the following equation (Barron, 2003):

$$L_W = 45 + 12.5 \cdot \log_{10} kVA$$

Equation 4

As recommended by Barron (2003), octave band L_W's were determined by subtracting the following from the total L_W; 63 Hz – 7 dB, 125 Hz – 3 dB, 250 Hz – 9 dB, 500 Hz – 13 dB, 1 kHz – 13 dB, 2 kHz – 19 dB, 4 kHz – 24 dB.

The steam strainer, main stop valve, main control valve, steam turbine, main oil pump, main oil tank vapour extractor, control oil pump, control oil radiator and generator will be contained within the turbine hall. The effective L_W of these sources combined when emitted through the turbine hall walls (façades) was estimated. In the calculation absorption and transmission losses were accounted for. A summary of information used in the estimation of the effective turbine hall L_W is given in Table 6.

Table 6: Data used in the calculation of the effective L_W of the galvanised steel clad turbine hall

Turbine hall dimensions	Length 30 m Width 18 m Height 18 m Internal surface area 2 808 m^2						
	63 Hz	**125 Hz**	**250 Hz**	**500 Hz**	**1 kHz**	**2 kHz**	**4 kHz**
Combined L_W of sources within the turbine hall (dB)	112.5	119.9	106.0	102.3	102.8	97.4	93.2
Average absorption coefficient	0.35	0.35	0.39	0.44	0.49	0.54	0.57
Transmission coefficient of 20 g galvanised steel	8	14	20	26	32	38	38

A summary of sources and associated L_W's as determines from the above and included in simulations is given in Table 7. The reader is reminded that the Ormat and Sosian Geothermal Power Plants were assumed to be exact copies of the QPEA Menengai Geothermal Power Plant.

Table 7: Final source inventory summary for the facility(s)

Source	Qty. per facility	Octave Band Sound Power Levels; LWi (dB)							LWA (dBA)
		63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
Droplet Separator	1	72.0	58.0	52.6	53.2	62.0	60.8	58.1	66.2
Main Condenser	1	91.2	91.2	95.8	98.4	99.2	97.0	94.2	103.4
Ejector	3	95.0	95.0	102.6	111.2	115.0	112.8	113.1	119.5
Inter Condenser	1	87.0	87.0	95.6	103.2	107.0	104.8	105.1	111.5
Vacuum Pump	4	90.0	97.0	96.6	97.2	94.0	89.8	86.2	98.8

Source	Qty. per facility	Octave Band Sound Power Levels; LWi (dB)							LWA (dBA)
		63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
Hotwell Pump	2	64.0	90.0	97.6	91.2	87.0	79.8	71.3	93.2
Auxiliary Cooling Water Pump	2	110.0	102.0	95.6	87.2	82.0	79.8	77.2	92.4
Cooling Tower per Cell	4	103.5	100.9	98.8	98.0	99.7	99.1	98.9	106.1
Turbine Hall (effective L_W)	1	110.9	112.3	92.1	82.1	76.3	64.7	60.3	96.9
Transformers (11 kV to 132 kV)	1	99.7	103.7	97.7	93.7	93.7	87.7	82.7	97.7
Transformers (11 kV to 0.69 kV)	1	86.0	90.0	84.0	80.0	80.0	74.0	69.0	84.0
Transformers (11 kV to 00.415 kV)	1	72.8	76.8	70.8	66.8	66.8	60.8	55.8	70.8

4.2 Noise Propagation and Simulated Noise Levels

The propagation of noise from the operational phase was calculated in accordance with SANS 10355 (2004). Meteorological and site specific acoustic parameters as discussed in Section 3.2.1 along with source data discussed in 4.1, were applied in the model.

Based on the anticipated extent of impacts given the baseline, the propagation of noise was calculated over a distance of approximately 5 km at 50 m intervals. Results are presented in tabular and isopleths form. An isopleth is a line on a map connecting points at which a given variable (in this case L_P) has a specified constant value. This is analogous to contour lines on a map showing terrain elevation. In the assessment of environmental noise, isopleths present lines of constant noise level as a function of distance.

Table 8 gives a summary of maximum downwind distances over which Kenyan sound level limits and IFC noise level guidelines are exceeded should the QPEA Geothermal Power Plant be operational on its own and with the Sosian and Ormat facilities. Since the latter is representative of the ‘worst case’ isopleths of this scenario is included in Figure 6 to Figure 11.

From Table 8 it is evident that even with all three facilities operating simultaneously the overall maximum increase in noise level over the baseline will reduce to less than 3 dBA at around 1.72 km from the boundary of operations. As expected the noise impact would be most notable at night when baseline noise levels are lower and assessment criteria more stringent. Since the closest NSRs are situated at least 3 km away from these sites it is however unlikely a change in day or night time noise levels will be detected at these locations. SANS 10103 (2008) indicates that at an increase of between 0 and 5 dBA, sporadic complaints with little or no community action may be expected.

The relatively small impact area is the combined result of the baseline noise levels (already in exceedance of assessment criteria), the design specifications of the facilities (i.e. galvanised steel sheet cladding of building that contains major noise sources), and the absence of permanent NSRs within 2 km radius from site.

It can therefore be concluded that, when referring to noise levels and increases in ambient noise levels as a result of the geothermal power plants’ operational design parameters, such as turbine hall cladding with galvanised steel sheets, will be sufficient to ensure that no annoyance will be caused at the closest NSRs.

Table 8: Maximum downwind distances over which Kenyan and IFC noise criteria are exceeded

Source	Kenya Sound Level Limits		IFC Noise Level Guidelines	
	Day-time (50 dBA)	Night-time (35 dBA)	Day-time (55 dBA)	Night-time (45 dBA)
QPEA (Quantum) Geothermal Power Plant				
Incremental	50 dBA at 760 m	35 dBA 2 430 m	55 dBA at 520 m	45 dBA at 1 250 m
Cumulative (in addition to baseline)	Baseline of 55.2 dBA exceeds limit	Baseline of 45.2 dBA exceeds limit	Baseline of 55.2 dBA exceeds guideline	Baseline of 45.2 dBA exceeds guideline
Increase above baseline	Not applicable	Not applicable	3 dBA at 510 m	3 dBA at 1 230 m
QPEA (Quantum), Sosian and Ormat Geothermal Power Plants				
Incremental	50 dBA at 1 080 m	35 dBA 3 160 m	55 dBA at 730 m	45 dBA at 1 760 m
Cumulative (in addition to baseline)	Baseline of 55.2 dBA exceeds limit	Baseline of 45.2 dBA exceeds limit	Baseline of 55.2 dBA exceeds guideline	Baseline of 45.2 dBA exceeds guideline
Increase above baseline	Not applicable	Not applicable	3 dBA at 730 m	3 dBA at 1 720 m

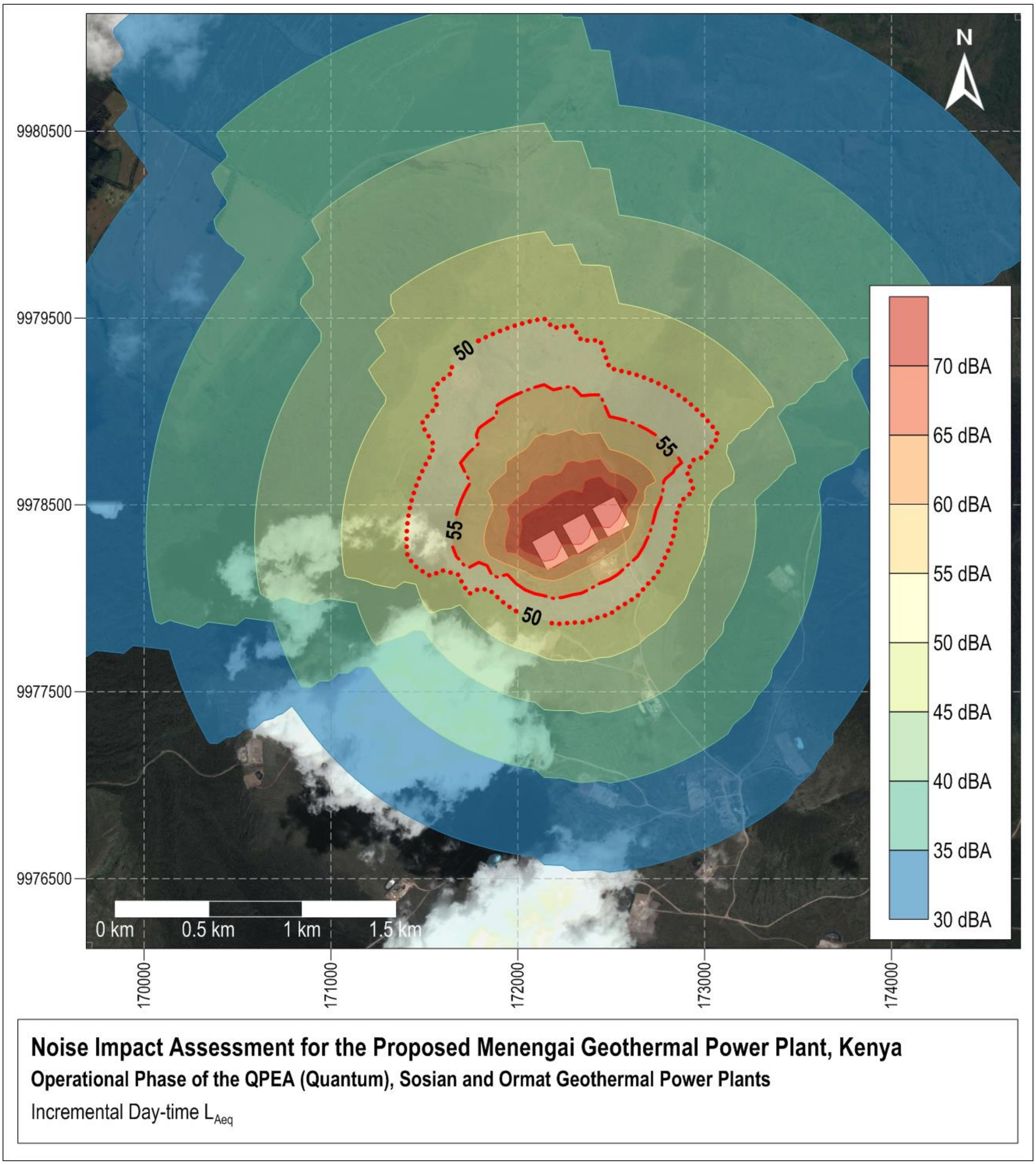


Figure 6: Incremental day-time L_{Aeq} as a result of the operational phase of the QPEA (Quantum), Sosian and Ormat Geothermal Power Plants

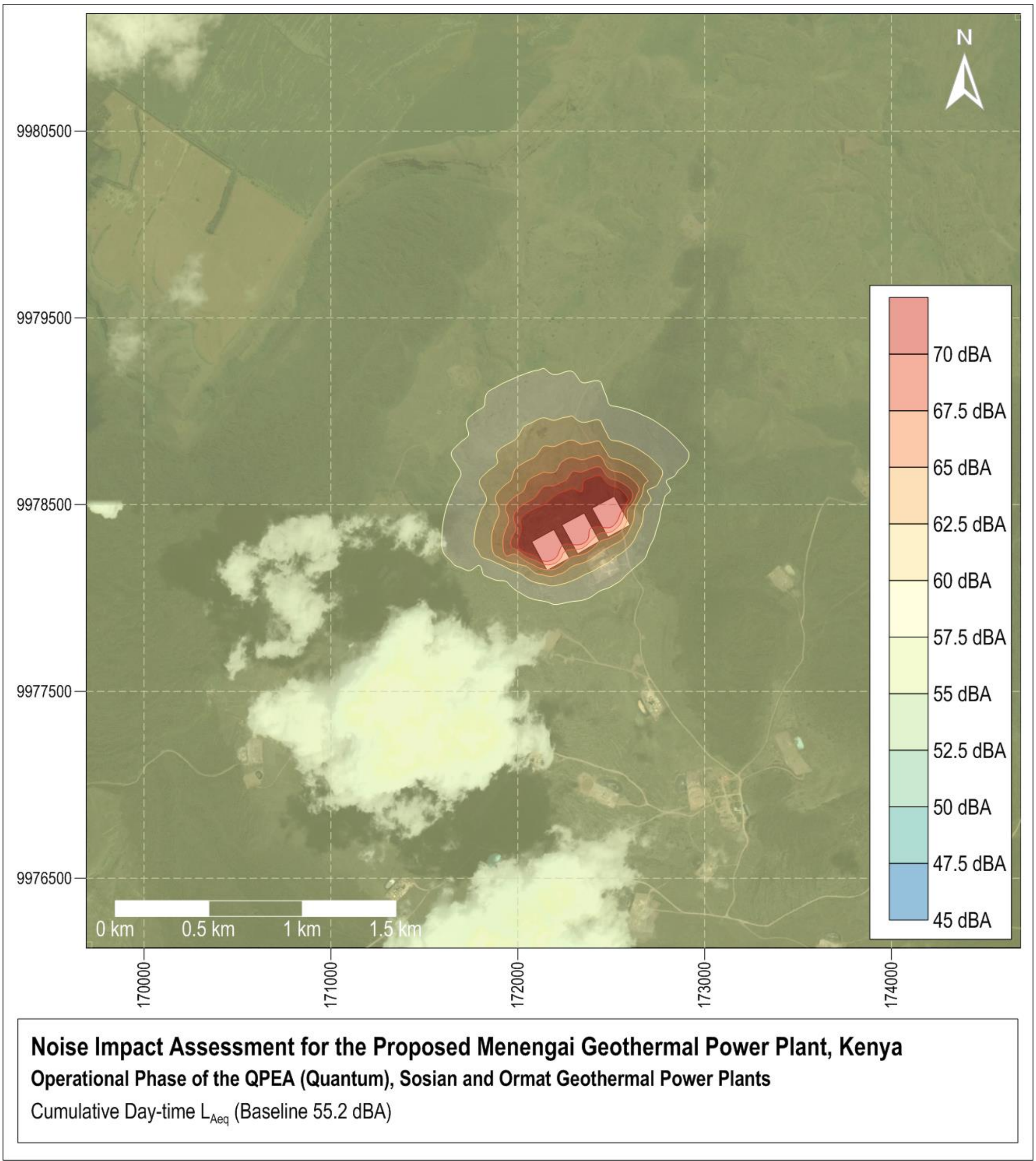


Figure 7: Cumulative day-time L_{Aeq} as a result of the operational phase of the QPEA (Quantum), Sosian and Ormat Geothermal Power Plants in addition to the baseline of 55.2 dBA

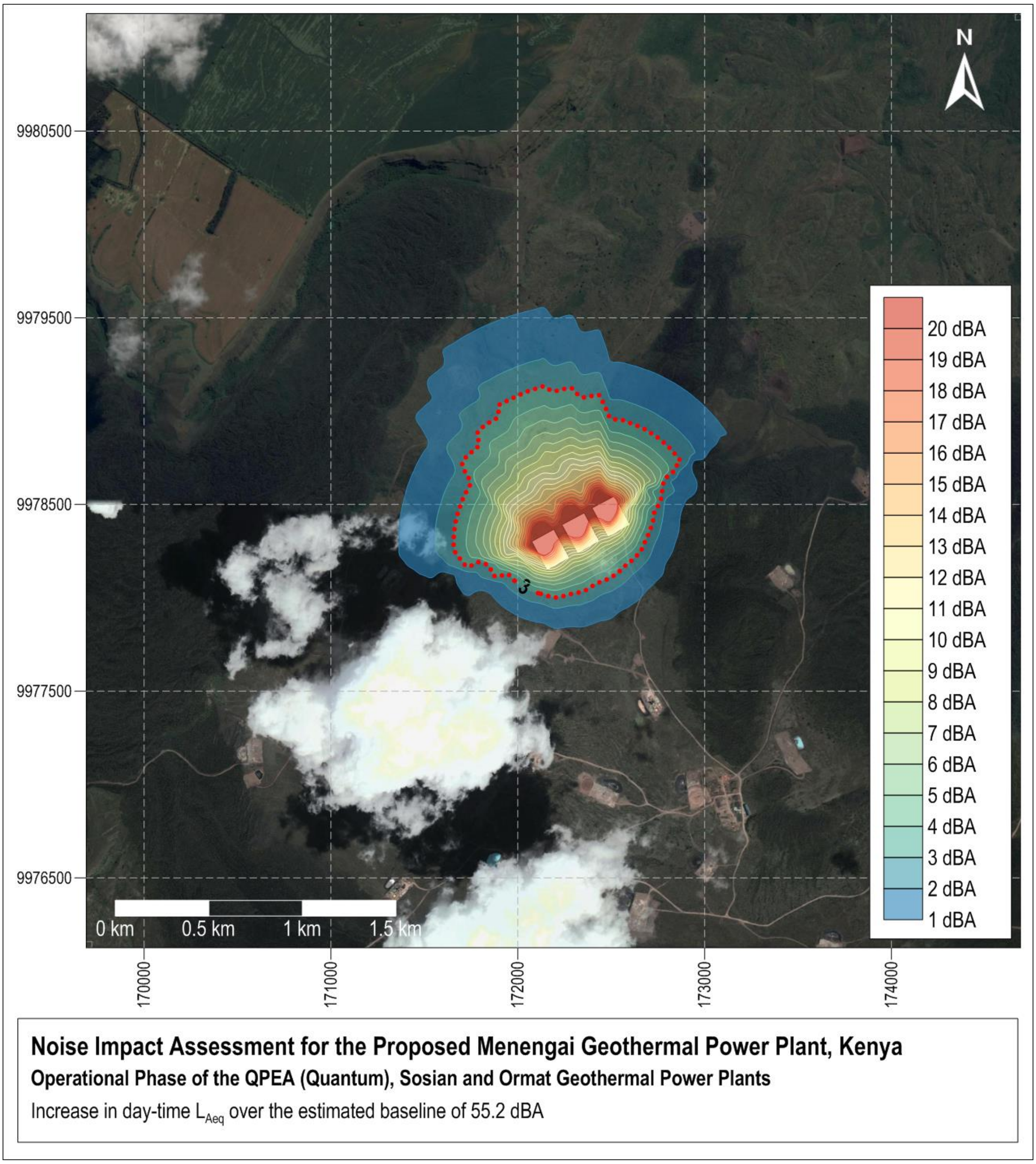


Figure 8: Increase in day-time L_{Aeq} over the baseline of 55.2 dBA as a result of the operational phase of the QPEA (Quantum), Sosian and Ormat Geothermal Power Plants

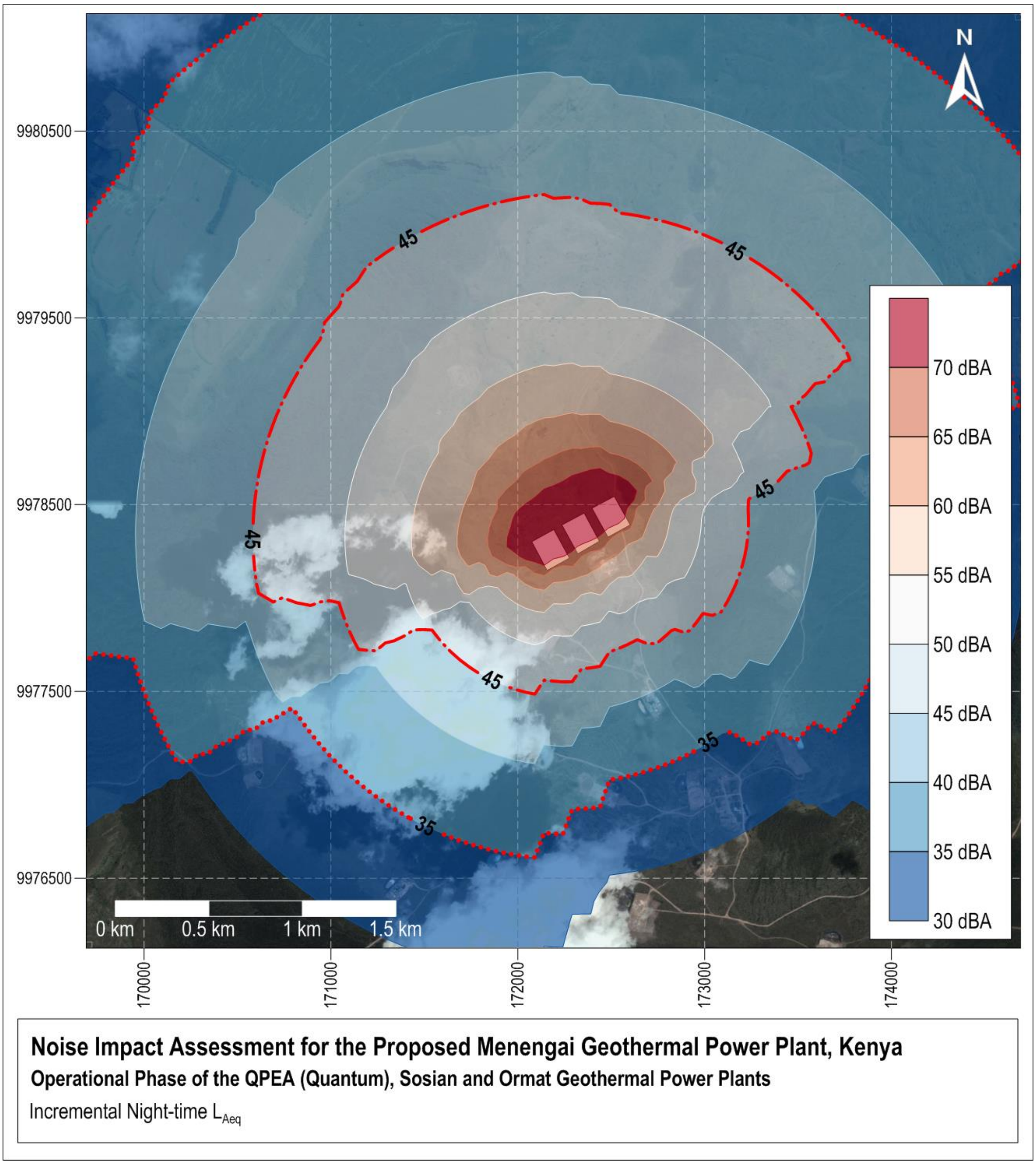


Figure 9: Incremental night-time L_{Aeq} as a result of the operational phase of the QPEA (Quantum), Sosian and Ormat Geothermal Power Plants

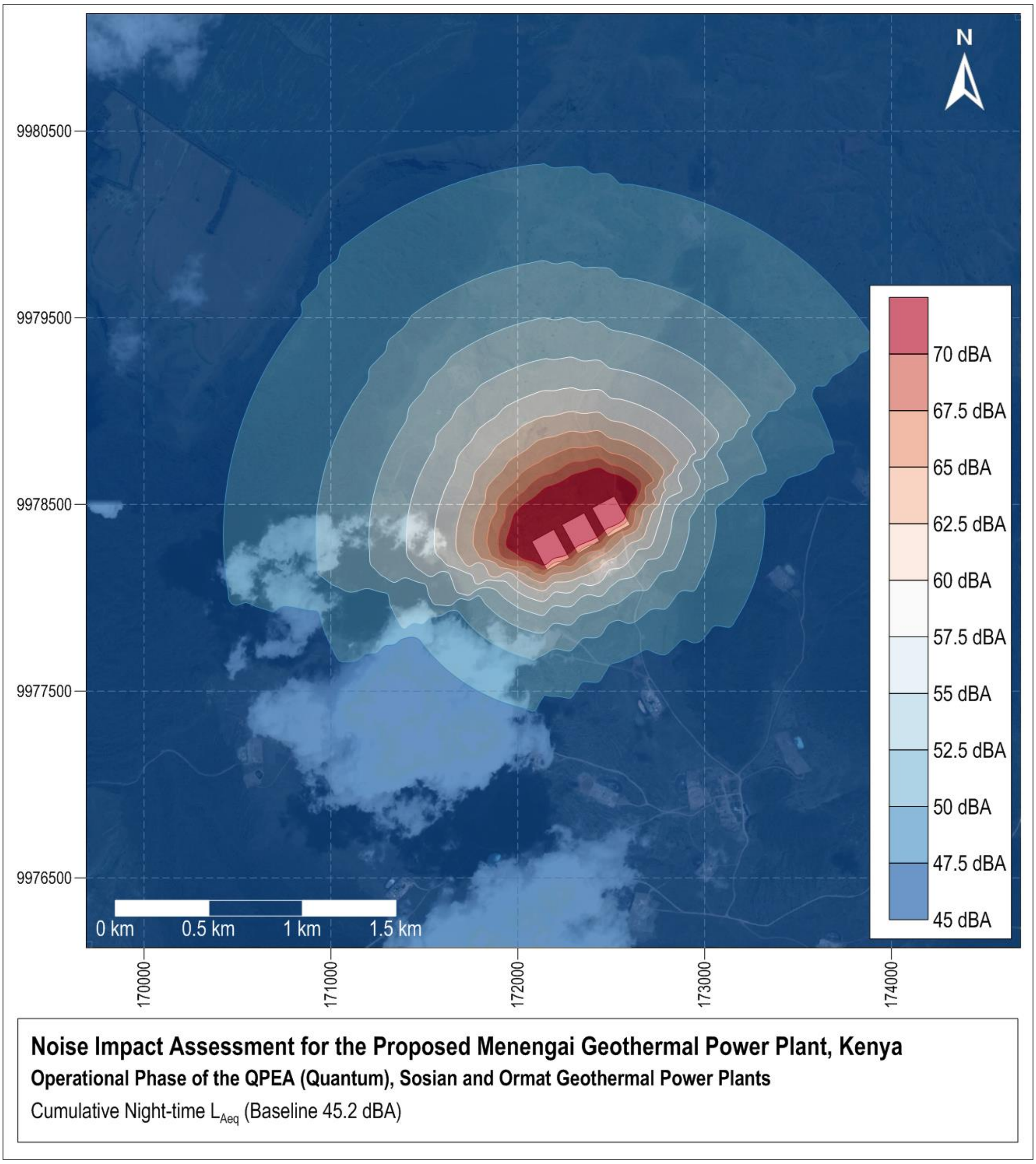


Figure 10: Cumulative night-time L_{Aeq} as a result of the operational phase of the QPEA (Quantum), Sosian and Ormat Geothermal Power Plants in addition to the baseline of 45.2 dBA

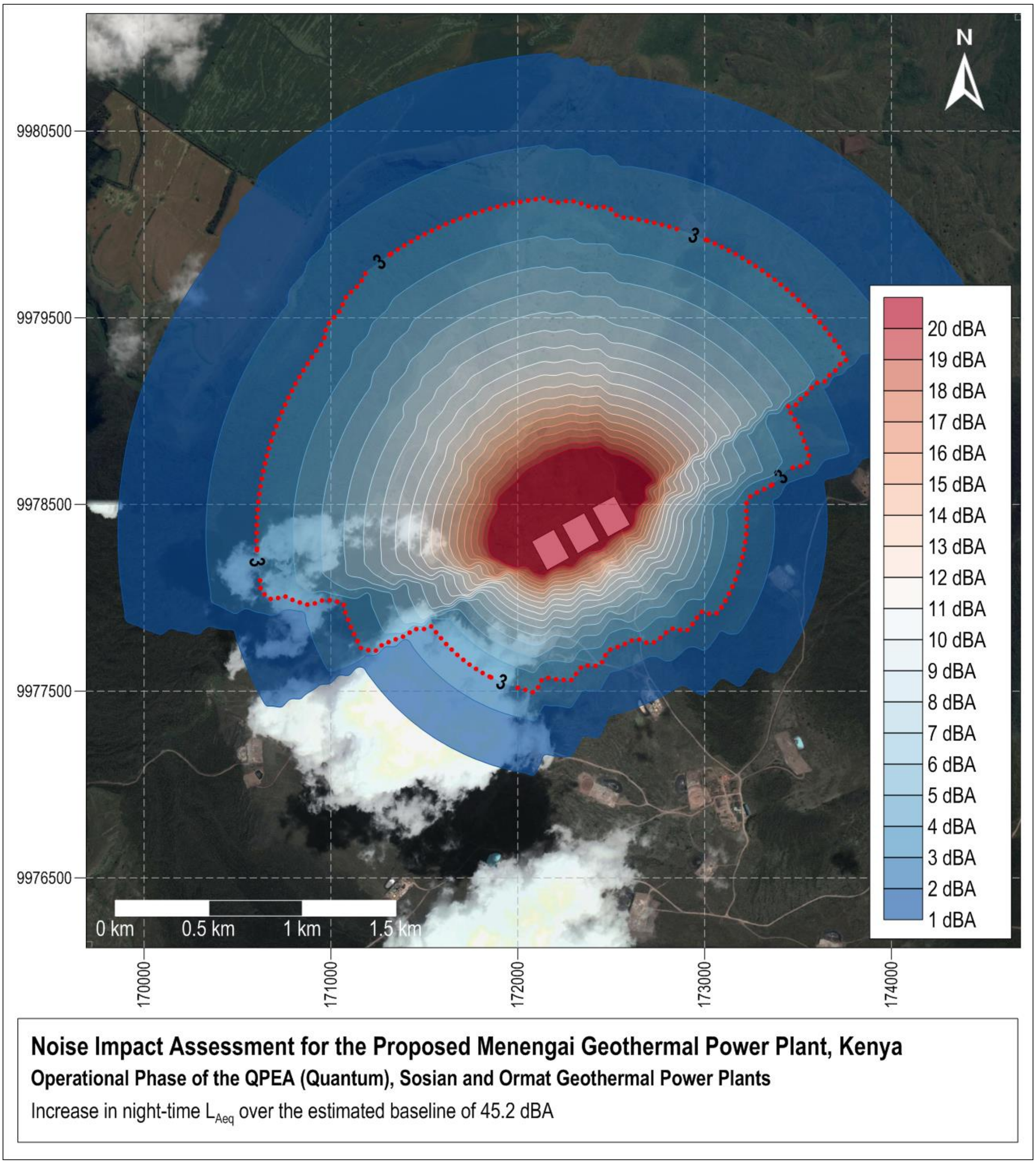


Figure 11: Increase in night-time L_{Aeq} over the baseline of 45.2 dBA as a result of the operational phase of the QPEA (Quantum), Sosian and Ormat Geothermal Power Plants

5 MANAGEMENT, MITIGATION AND RECOMMENDATIONS

In the quantification of noise emissions and simulation of noise levels as a result of proposed geothermal power generation activities it was found that incrementally, both Kenyan and IFC assessment criteria for human exposure will not be exceeded at NSRs. Since baseline noise levels are however already in exceedance of these criteria, cumulative noise levels will as expected also be. The maximum increase above the baseline will reduce to less than 3 dBA (IFC criterion) at around 1.72 km from the boundary of operations. The increase at all NSRs will be less than 1 dBA both during the day and night. SANS 10103 (2008) indicates that at an increase of between 0 and 5 dBA, sporadic complaints with little or no community action may be expected.

To however minimise and ensure low impacts of both construction and operational noise on the receiving environment it is recommended that the following measures be adopted as part of the GPEA noise management plan.

5.1 Good Engineering and Operational Practices

For general construction and operational activities the following good engineering practice should be applied:

- All diesel powered construction equipment and plant vehicles must be kept at a high level of maintenance. This must particularly include the regular inspection and, if necessary, replacement of intake and exhaust silencers. Any change in the noise emission characteristics of equipment must serve as trigger for withdrawing it for maintenance.
- To minimise noise generation, vendors must be required to guarantee optimised equipment design noise levels.
- Acoustic attenuation devices should be installed on all ventilation outlet and high pressure gas or liquid should not be ventilated directly to the atmosphere, but through an attenuation chamber or device.
- Vibrating equipment must be on vibration isolation mountings.
- The site layout should be designed in such a manner that the noisiest sections of the plant are at the centre of the site, using surrounding buildings as noise attenuation shields.
- A mechanism to monitor noise levels, record and respond to complaints and mitigate impacts should be developed.

5.2 Operational Hours

It is recommended that, **as far is as feasible**, noise generating activities be limited to day-time hours (considered to be between 06:01 and 20:00) since noise impacts are most significant during the night. This includes:

- Limiting all construction activities to day-time hours;
- Limiting truck and other vehicle activity to and from the site during the operational phase to day-time hours.

5.3 Acoustic Barriers

The effect of the steel sheet cladding of the turbine hall which encloses major noise sources was included in the assessment and proven to be sufficient to ensure that assessment criteria are not exceeded at NSRs. It is essential that the cladding be installed in such a way that gaps and openings are minimised. Access doors must be kept closed at all times.

5.4 Traffic

Although traffic volumes are expected to be low during the operational phase, construction phase traffic may be notable. The measures described below are considered good practice in reducing traffic related noise.

In general, road traffic noise is the combination of noise from individual vehicles in a traffic stream and is considered as a line source if the density of the traffic is high enough to distinguish it from a point source. The following general factors are considered the most significant with respect to road traffic noise generation:

- Traffic volumes i.e. average daily traffic.
- Average speed of traffic.
- Traffic composition i.e. percentage heavy vehicles.
- Road gradient.
- Road surface type and condition.
- Individual vehicle noise including engine noise, transmission noise, contact noise (the interaction of tyres and the road surface, body, tray and load vibration and aerodynamic noise

In managing transport noise specifically related to trucks, efforts should be directed at:

- Minimizing individual vehicle engine, transmission and body noise/vibration. This is achieved through the implementation of an equipment maintenance program.
- Minimize slopes by managing and planning road gradients to avoid the need for excessive acceleration/deceleration.
- Maintain road surface regularly to avoid corrugations, potholes etc.
- Avoid unnecessary idling times.
- Minimizing the need for trucks/equipment to reverse. This will reduce the frequency at which disturbing but necessary reverse warnings will occur. Alternatives to the traditional reverse 'beeper' alarm such as a 'self-adjusting' or 'smart' alarm could be considered. These alarms include a mechanism to detect the local noise level and automatically adjust the output of the alarm is so that it is 5 to 10 dB above the noise level in the vicinity of the moving equipment. The promotional material for some smart alarms does state that the ability to adjust the level of the alarm is of advantage to those sites 'with low ambient noise level' (Burgess & McCarty, 2009).

5.5 Monitoring

It is recommended that short term 24-hour to 1-week sampling be conducted at the on the facility boundaries as well as nearest NSRs. Monitoring should be conducted in accordance with the procedures specified by the IFC (2007)). Samples, at least 24-hours in duration should include the following parameters: L_{Aeq}, L_{A90}, and the un-weighted octave band sound pressure levels (L_{Zeq}). In the interpretation and reporting of sampled environmental noise levels, use should be made of a trained specialist. In addition to ambient noise monitoring it is recommended that source noise measurements of turbine building facades and sources located inside and outside buildings be sampled to verify L_W's applied in this study.

5.6 Application for a Licence to Emit Noise Levels in Excess of Kenyan Limits

It is unclear exactly when a facility may be required to apply for such a licence. **It is recommended that local authorities be consulted in this regard given the outcome of this noise assessment**.

6 REFERENCES

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7 APPENDIX A – NOISE MEASUREMENT DATA

To be included