Air Quality Impact Assessment for the Proposed Kaishan Renewable Energy Development Geothermal Power Plant in Kenya

Project done for **Kaishan Renewable Energy Development (KRED)**

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Abbreviations

Airshed	Airshed Planning Professionals (Pty) Ltd
ACGIH	American Conference of Governmental Industrial Hygienists
ADMS	Atmospheric Dispersion Modelling System
AQSR	Air Quality Sensitive Receptor
ASG	Atmospheric Studies Group
CERC	Cambridge Environmental Research Consultants
EHS	Environmental, Health, and Safety
GDC	Geothermal Development Company
GV	Guideline Value
IFC	International Finance Corporation
IPP	Independent Power Producer
IRIS	Integrated Risk Information System (US EPA)
KRED	Kaishan Renewable Energy Development
L_{MO}	Monin-Obukhov Length
LTEL	Long-Term Exposure Limit
MM5	Mesoscale Model 5
NCG	Non-Condensable Gases
NEMA	National Environment Management Authority (Kenya)
NIOSH	National Institute for Occupational Safety and Health
OEHHA	California Office of Environmental Health Hazard Assessment
OSHA	Occupational Safety and Health Act
PEL	Permissible Exposure Limit
REL (NIOSH)	Recommended Exposure Limit
REL (OEHHA)	Reference Exposure Level
RfC	Reference Concentration
TLV	Threshold Limit Value
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WHO	World Health Organization

Executive Summary

An air quality impact assessment was conducted for operational phase activities planned for the proposed OrPower Twenty Two Limited (OTTL) geothermal power plant north of Nakuru in Kenya in 2019. The main objective of this study was to quantify the extent to which ambient pollutant levels will increase as a result of the project. The project was done specifically for OTTL's power plant but also includes the other two Independent Power Producers (IPPs); Quantum and Sosian; which are proposed adjacent to OTTL. It is understood that due to a lack of adequate funding the project did not reach financial closure and subsequently the 100% shareholding of OTTL changed from Symbion Power to Kaishan Renewable Energy Development (KRED). Kaishan are in the process of finalising the key agreements and look at starting construction within a short period. The proposed technology is different from the one Symbion had and has changed from the single flash unit to five units three utilising the ORC technology through heat exchangers and two utilising the screw expander. KRED therefore requires updated air quality dispersion modelling to be conducted for the proposed Geothermal Power Plant to be located at the Menengai Area in Nakuru. The proposed technology change will change emission stack parameters, and therefore the dispersion potential.

The air quality impact assessment included a study of the receiving environment and the quantification and assessment of the impact of the proposed Menengai geothermal power plant on human health and the environment. The receiving environment was described in terms of local atmospheric dispersion potential, the location of potential air quality sensitive receptors (AQSRs) in relation to proposed activities as well as pre-development ambient pollutant levels. The following was found:

- The wind direction for the area is predominantly from the south and northeast. Long term air quality impacts are therefore expected to the north and southwest of the proposed operations.
- Ambient air quality monitoring conducted at the wells by the Geothermal Development Company (GDC), from 2016 to 2019 indicated ambient air pollutant levels that exceed the odour threshold as well as the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) of 1 ppm.
- Several AQSRs are situated within the vicinity of the proposed power plant (several homesteads in the caldera, 3.5 km southwest of the plant, and areas outside of caldera 2 km northwest of the plant, Marigo, and 2.5 km north-northeast of the plant, Rigogo).

A comprehensive atmospheric emissions inventory was then compiled for the operational phase of the project. Pollutants quantified included the main pollutant of concern, hydrogen sulfide (H_2S).

Estimated emissions along with information on the receiving environment were used as input to an atmospheric dispersion model which simulated ground level pollutant concentrations.

The following scenario were modelled:

- Scenario 1 – all three IPP (Quantum emitting from a single stack and Kaishan and Sosain emitting from multiple vents)
- Scenario 2 – only Kaishan's impact emitting from 40 vents

Simulated ground level pollutant concentrations were screened against internationally accepted reference inhalation concentrations. The main findings of the impact study are listed below.

- Health Impact:
  - For Scenario 1, with Quantum emitting from a single stack and Kaishan and Sosian emitting from multiple vents, simulated 24-hour ambient H_2S concentrations exceed the Iceland guideline of 50 µg/m³ at some

of the AQSRs. However, the Kenyan Tolerance Limit and World Health Organization (WHO) daily guideline value of 150 µg/m³ is not exceeded at any of the AQSRs. Simulated annual average ambient H_2S concentrations exceed the California Office of Environmental Health Hazard Assessment (OEHHA) screening level for chronic exposure (10 µg/m³) at some of the AQSRs in the Rigogo area.
    - For Scenario 2, Kaishan's incremental impact, simulated 24-hour ambient H_2S concentrations do not exceed the Iceland guideline of 50 µg/m³ or Kenyan Tolerance Limit and the WHO daily guideline value of 150 µg/m³ at any of the AQSRs. Simulated annual average ambient H_2S concentrations exceed the OEHHA screening level for chronic exposure (10 µg/m³) at the Rigogo area.
- Occupational Impact:
    - For Scenario 1, the ACGIH TLV of 1ppm (1500 µg/m³) is exceeded both on-site as well as ~ 300 m from the site boundary. For Scenario 2, the ACGIH TLV of 1ppm (1500 µg/m³) is exceeded for a very small area just off-site. None of the scenarios exceed the WHO lowest observable adverse effect level (LOAEL) of 15 mg/m³ (15 000 µg/m³) or 10 ppm.
- Odour Impact:
    - The results of the modelling suggest it is possible that there will be a H_2S odour impact at the AQSRs.

To ensure the lowest possible impact on AQSRs and environment it is recommended that an air quality management plan should be adopted. In summary, this includes:

- The mitigation of sources of emission. Various mitigation options should be investigated further.
- Ambient air quality monitoring, including:
    - Installation of a H_2S gas monitoring network;
    - Continuous operation of the H_2S gas monitoring systems to facilitate early detection and warning; and
    - Emergency planning involving community input to allow for effective response to monitoring system warnings.

Table of Contents

List of Tables

List of Figures

1 INTRODUCTION

An air quality impact assessment was conducted for the proposed OrPower Twenty Two Limited (OTTL) geothermal power plant north of Nakuru in Kenya in 2019. The main objective of this study was to quantify the extent to which ambient pollutant levels will increase as a result of the project. The project was done specifically for OTTL's power plant but also includes the other two Independent Power Producers (IPPs); Quantum and Sosian; which are proposed adjacent to OTTL. It is understood that due to a lack of adequate funding the project did not reach financial closure and subsequently the 100% shareholding of OTTL changed from Symbion Power to Kaishan Renewable Energy Development (KRED). Kaishan are in the process of finalising the key agreements and look at starting construction within a short period. The proposed technology is different from the one Symbion had and has changed from the single flash unit to five units three utilising the ORC technology through heat exchangers and two utilising the screw expander. Airshed Planning Professionals (Pty) Ltd (Airshed) was appointed by KRED to update the air quality impact specialist study for the proposed Geothermal Power Plant in Kenya (hereafter referred to as the project).

The following tasks, typical of an air quality impact assessment, were included in the scope of work:

- A **review** of proposed project activities in order to identify sources of emission and associated emissions.
- A study of **regulatory requirements and health thresholds** for identified key pollutants against which compliance need to be assessed and health risks screened.
- Use of the **receiving environment** in the vicinity of the project; assumed the same as for the 2019 air quality impact assessment, including:
    - The identification of potential air quality sensitive receptors (AQSRs);
    - A study of the atmospheric dispersion potential of the area taking into consideration local meteorology, land-use and topography; and
    - The analysis of all available ambient air quality information/data to determine pre-development ambient pollutant levels.
- The compilation of a comprehensive **emissions inventory**.
- **Atmospheric dispersion modelling** to simulate ambient air pollutant concentrations as a result of the project.
- A **screening** assessment to determine:
    - Potential health risks as a result of exposure to non-carcinogenic non-criteria pollutants.
- The compilation of a comprehensive air quality specialist report detailing the study approach, limitations, assumption, results and recommendations of mitigation and management of air quality impacts.

1.1 Description of Project Activities from an Air Quality Perspective

The facility proposed for construction by Kaishan will generate 35 mega Watts (MW) using a steam turbine. The proposed layout of plant is shown in Figure 1.

The project can be divided into three distinct operational phases viz., a construction phase, an operational phase and a closure phase. A description of each of these phases is summarised below. However, the assessment was done for the operational phase.

1.1.1 Construction

Impacts from construction activities will be similar to those identified for the construction of roads and well sites as in the exploration phase but at a larger scale, including larger production wells. Construction activities with potential to create nuisance dust include:

- Formation (or expansion, if required) of production well pads, power plant, steam lines, switchyard and site access roads;
- Excavations for foundations and construction of power plant and steam line infrastructure;

As with exploration wells, once constructed the production wells will be commissioned by discharging to a well test silencer, and non-condensable gases (NCGs) and steam will be emitted to atmosphere, however the larger bore size will result in much larger volumes being released.

Again, although very unlikely, there is also the potential for a well blowout to occur during drilling, which will result in the unplanned release of geothermal fluids including NCGs.

During construction there will also be a number of sources of combustion gas emissions from the exhausts of drilling rig, transport vehicles, construction machinery, and electricity generators using diesel fuel. The number of vehicles, machinery, and generators required during the construction will be higher than those required for the exploration stage, and the drilling rig will be much larger.

1.1.2 Operation

There are a number of potential technology options for generating electrical energy from a geothermal resource. However, emissions from the project will potentially include the release of NCGs from sources such as steam vents and cooling towers. Although these can be considered 'natural' in the sense that they are already emitted from numerous existing fumaroles and vents, the power station will emit these in larger quantities than might be experienced naturally. Additionally, pipeline failures due to damage or corrosion could result in unplanned releases of steam and NCGs.

Combustion gas emissions during operation will be limited to emergency generators, firewater pumps, and service vehicles required for transporting maintenance equipment and materials.

1.1.3 Decommissioning

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.

Emissions generated by activities during the decommissioning and reclamation phase will include dust emissions from land clearing, structure removal, backfilling, dumping, and reclamation of disturbed areas (grading, seeding, and planting).

The proposed Kaishan Geothermal Power Plant is one of three such proposed Independent Power Producer (IPP) facilities. The location of two other facilities, referred to as the Quantum Power East Africa (QPEA) and Sosian Energy Limited (Sosian) Geothermal Power Plants, are shown in Figure 2. The cumulative impact of all three facilities was included in the assessment.

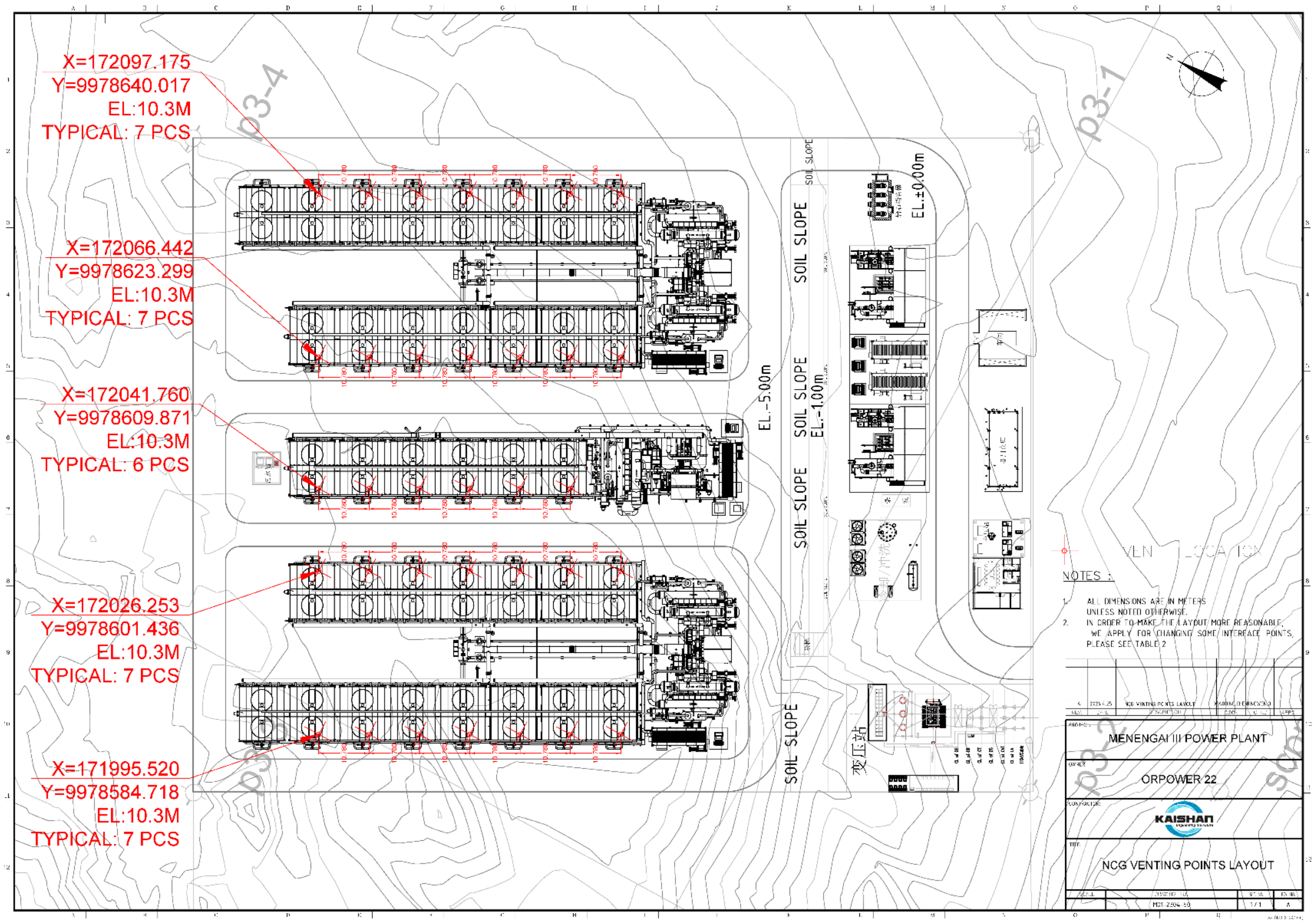

Figure 1: Proposed layout of the Kaishan Geothermal Power Plant (layout provided by Kaishan)

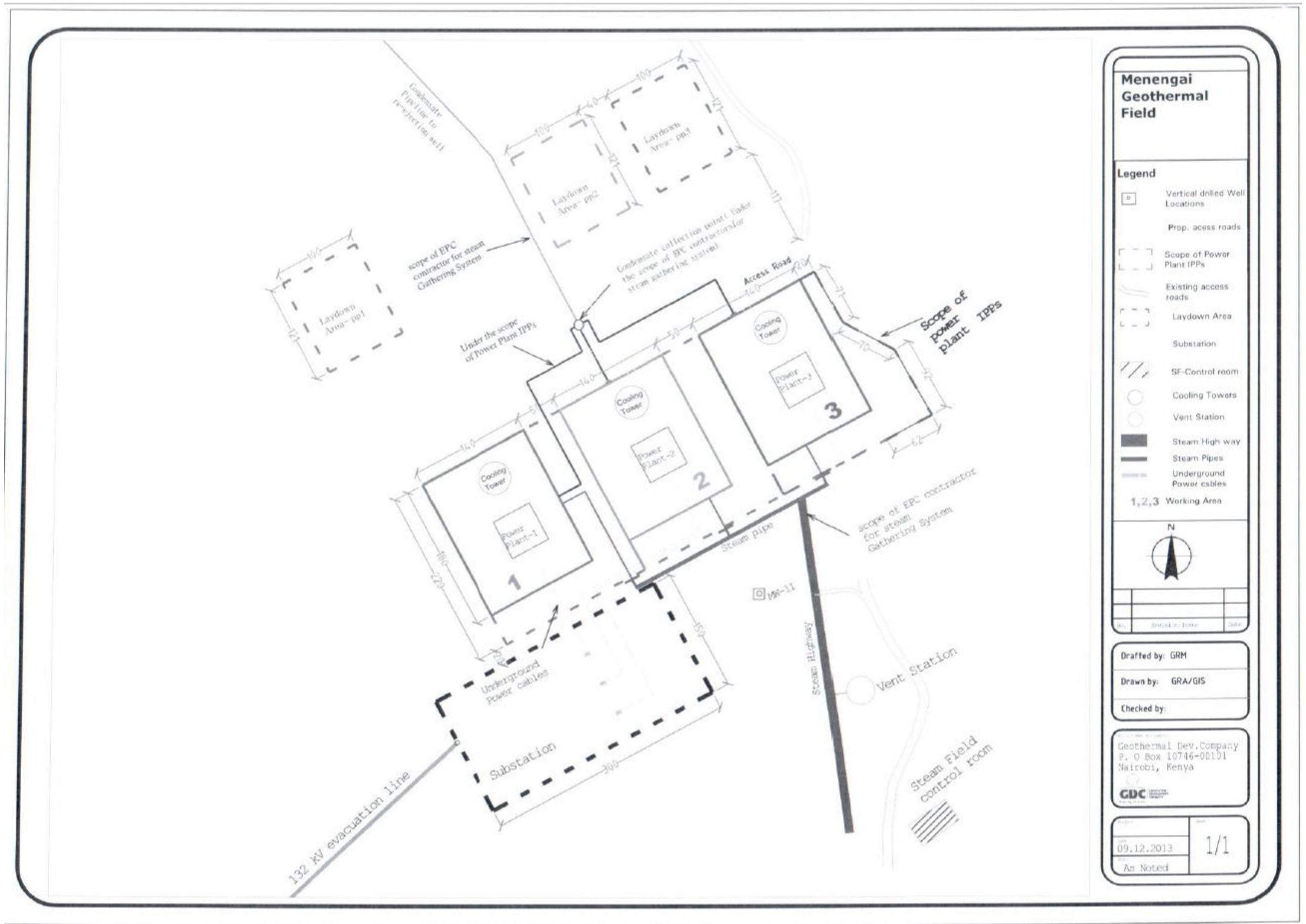

Figure 2: The Menengai Geothermal Field with the locations of the proposed Kaishan (Power Plant 1), QPEA (Quantum) (Power Plant 2) and Sosian (Power Plant 3) geothermal power plants

1.2 Approach and Methodology

The approach to, and methodology followed as part of the scope of work are discussed below.

1.2.1 Project Information and Activity Review

All project related information referred to in this study was provided by Kaishan.

1.2.2 The Identification of Regulatory Requirements and Health Thresholds

In the evaluation air emissions and ambient air quality impacts reference was made to:

- Screening levels for non-criteria pollutants published by various internationally recognised organisations;
- Odour thresholds and;
- Occupational limits.

1.2.3 Study of the Receiving Environment

Physical environmental parameters that influence the dispersion of pollutants in the atmosphere include terrain and meteorology. Existing pre-development ambient air quality in the study area was also considered. Readily available terrain data was obtained from the Atmospheric Studies Group (ASG) via the United States Geological Survey (USGS) web site at (ASG, 2011).

An understanding of the atmospheric dispersion potential of the area is essential to an air quality impact assessment. In the initial study done for Quantum (Petzer & Bornman, 2015), in the absence of on-site meteorological data (that is required for atmospheric dispersion modelling), use was made of simulated MM5 data for a period between 2011 and 2013. The MM5 (short for Fifth-Generation Penn State/NCAR Mesoscale Model) is a regional mesoscale model used for creating weather forecasts and climate projections. It is a community model maintained by Penn State University and the National Centre for Atmospheric Research. Since then, on-site meteorological data has been recorded at the Control Room and 2017 data was used for the study.

1.2.4 Determining the Impact of the Project on the Receiving Environment

The establishment of a comprehensive emission inventory formed the basis for the assessment of the air quality impacts from the project's emissions on the receiving environment.

In the simulation of ambient air pollutant concentrations use was made of the ADMS 5 (Atmospheric Dispersion Modelling System version 5) developed by the Cambridge Environmental Research Consultants (CERC). CERC was established in 1986, with the aim of making use of new developments in environmental research from Cambridge University and elsewhere for practical purposes. This model simulates a wide range of buoyant and passive releases to the atmosphere either individually or in combination. It has been the subject of a number of inter-model comparisons (CERC, 2004) (Hall, et al., 2000), one conclusion of which is that it tends provide conservative values under unstable atmospheric conditions in that, in comparison to the older regulatory models, it predicts higher concentrations close to the source.

ADMS 5 is a new generation air dispersion model which means that it differs from the regulatory models traditionally used in a number of aspects, the most important of which are the description of atmospheric stability as a continuum rather than discrete classes (the atmospheric boundary layer properties are described by two parameters; the boundary layer depth and the Monin-Obukhov length, rather than in terms of the single parameter Pasquill Class) and in allowing more realistic asymmetric plume behaviour under unstable atmospheric conditions. Dispersion under convective meteorological conditions uses a skewed Gaussian concentration distribution (shown by validation studies to be a better representation than a symmetric Gaussian expression).

Concentration distributions for various averaging periods may be calculated. All models have some inherent uncertainty, arising from shortcomings in the input data and in the physical modelling itself. It has generally been found that the accuracy of off-the-shelf dispersion models improve with increased averaging periods. The accurate prediction of instantaneous peaks is the most difficult and are normally performed with more complicated dispersion models specifically fine-tuned and validated for the location. For purposes of this report, the shortest time period modelled is one hour.

There will always be some error in any geophysical model, but it is desirable to structure the model in such a way to minimise the total error. A model represents the most likely outcome of an ensemble of experimental results. The total uncertainty can be thought of as the sum of three components: the uncertainty due to errors in the model physics; the uncertainty due to data errors; and the uncertainty due to stochastic processes (turbulence) in the atmosphere. The stochastic uncertainty includes all errors or uncertainties in data such as source variability, observed concentrations, and meteorological data. Even if the field instrument accuracy is excellent, there can still be large uncertainties due to unrepresentative placement of the instrument (or taking of a sample for analysis). Model evaluation studies suggest that the data input error term is often a major contributor to total uncertainty. Even in the best tracer studies, the source emissions are known only with an accuracy of ±5%, which translates directly into a minimum error of that magnitude in the model predictions. It is also well known that wind direction errors are a major cause of poor agreement, especially for relatively short-term predictions (minutes to hourly) and long downwind distances. All of the above factors contribute to the inaccuracies not even associated with the mathematical models themselves.

Input data types required for the ADMS model include source data, meteorological data, terrain data and information on the nature of the receptor grid.

1.2.5 Compliance Assessment and Health Risk Screening

Health risk screening was done through the comparison of simulated non-criteria pollutant concentrations of hydrogen sulfide (H_2S) to inhalation screening levels. Potential for odour impacts was done through the comparison of simulated non-criteria pollutant concentrations (H_2S) to odour thresholds. Occupational limits were used to assess the occupational impact.

1.3 Assumptions, Exclusions and Limitations

- The quantification of sources of emission was restricted to proposed operations at the geothermal power plants.
- Emissions for proposed operations were provided by Kaishan. Information was provided by the other two independent power producers (IPPs) located adjacent to the Kaishan site (Quantum and Sosian).
- Routine emissions were estimated and simulated.
- Baseline data (i.e. meteorological and sampled baseline data) as obtained from the 2019 air quality impact assessment were used for the current assessment and were assumed to be representative of current baseline conditions.
- The impact assessment was limited to H_2S during the operational phase.

2 Impact Assessment Criteria

Prior to assessing the impact of proposed activities at the geothermal power plant on human health and the environment, reference needs to be made to the environmental regulations governing the impact of such operations i.e. emission standards and ambient air quality standards.

Emission standards are generally provided for point sources and specify the amount of the pollutant acceptable in an emission stream and are often based on proven efficiencies of air pollution control equipment.

Air quality guidelines and standards are fundamental to effective air quality management, providing the link between the source of atmospheric emissions and the user of that air at the downstream receptor site. The ambient air quality standards and guideline values indicate safe daily exposure levels for the majority of the population, including the very young and the elderly, throughout an individual's lifetime. Air quality guidelines and standards are normally given for specific averaging or exposure periods.

2.1 Local Legislation Pertaining to Atmospheric Emissions and Air Quality

The regulation that controls ambient air quality in Kenya is referred to as "the Environmental Management and Co-ordination (Air Quality) Regulations, 2014" (NEMA, 2014). The objective of the Regulations is to provide for prevention, control and abatement of air pollution to ensure clean and healthy ambient air. It provides for the establishment of emission standards for various sources such as mobile sources (e.g. motor vehicles) and stationary sources (e.g. industries) as outlined in the Environmental Management and Coordination Act, 1999. It also covers any other air pollution source as may be determined by the Minister in consultation with the Authority. Emission limits for various areas and facilities have been set. The regulations provide the procedure for designating controlled areas, and the objectives of air quality management plans for these areas.

Kenyan Ambient air quality tolerance limits applicable to the project are 150 µg/m³ for 24-hour averages for hydrogen sulfide (H_2S). Although the legend is unclear on the regulations document on the website, it appears that the limit may not be exceeded more than three times in one year.

No emission limits are specified for geothermal power plants, although a geothermal power plant is considered a controlled facility and will have to monitor emissions and apply for an air emission licence.

2.2 World Bank Requirements

2.2.1 Environmental, Health and Safety Guidelines

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP). When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. The General EHS Guidelines are designed to be used together with the relevant Industry Sector EHS Guidelines which provide guidance to users on EHS issues in specific industry sectors.

The applicable EHS Guidelines comprise:

- Environmental, Health and Safety (EHS) General Guidelines; and
- EHS Guidelines for Geothermal Power Generation.

The EHS General Guidelines require that projects are assessed against the national ambient air quality guidelines or standards for the country in which they will operate, or in their absence, the WHO Ambient Air Quality Guidelines. It also provides general guidance on assessment, mitigation, and monitoring of specific air pollutants.

Specific to air quality the EHS Guidelines for Geothermal Power Generation provide recommendations for management of air quality emissions.

The IFC EHS Guidelines for Geothermal Power Generation (IFC, 2007) identifies drilling, flow testing and open contact or cooling tower systems as the sources of emissions in a geothermal power station. However, the document does not specify emission guidelines, but offers the following recommendations for the management of air emissions:

- Considering technological options that include total or partial re-injection of gases with geothermal fluids within the context of potential environmental impacts from alternative generating technologies together with other primary factors, such as the fit of the technology to the geologic resource and economic considerations (e.g. capital and operation / maintenance costs);
- When total re-injection is not feasible, venting of H_2S and non-condensable volatile mercury if, based on an assessment of potential impact to ambient concentrations, pollutant levels will not exceed applicable safety and health standards; and
- If necessary, use of abatement systems to remove H_2S and mercury emissions from non-condensable gases. Examples of H_2S controls can include wet or dry scrubber systems or a liquid phase reduction / oxidation system, while mercury emissions controls may include gas stream condensation with further separation or adsorption methods.

Furthermore, IFC (2007) recommends the following planning process and precautions as a result of the potential for H_2S exposure to the community:

- Siting of potential significant emissions sources with consideration of hydrogen sulfide gas exposure to nearby communities (considering key environmental factors such as proximity, morphology and prevailing wind directions);
- Installation of a hydrogen sulfide gas monitoring network with the number and location of monitoring stations determined through air dispersion modeling, taking into account the location of emissions sources and areas of community use and habitation;
- Continuous operation of the hydrogen sulfide gas monitoring systems to facilitate early detection and warning; and
- Emergency planning involving community input to allow for effective response to monitoring system warnings.

2.3 Exposure Guidelines and Standards

A clear distinction should be made between occupational exposure and community exposure standards or guidelines. Because it is assumed that exposure in the workplace is limited to working hours and workers are assumed to be a more robust population group, occupational guidelines or standards are often an order of magnitude or higher than community exposure standards. All guidelines and standards discussed below are specifically for H_2S as this is the pollutant of concern.

2.3.1 Occupational Standards and Guidelines

Kenya

The factories and other places of work (hazardous substances) rules ,2007 (NEMA, 2007), set a recommended exposure limit (REL) of 10 ppm, (15 mg/m³) (TWA).

United States

In terms of the Occupational Safety and Health Act (OSHA), the permissible exposure limits (PEL) are given for different industrial sectors as follows:

General Industry: Exposures shall not exceed 20 ppm (27.88 mg/m³) (ceiling) with the following exception: if no other measurable exposure occurs during the 8-hour work shift, exposures may exceed 20 ppm (27.88 mg/m³), but not more than 50 ppm (69.70 mg/m³) (peak), for a single time period up to 10 minutes. These standards would be applicable to the Menengai facility if it were located in the US.

The American Conference of Governmental Industrial Hygienists (ACGIH) in February 2010 set a Threshold Limit Value (TLV) of 1 ppm (1.5 mg/m³) TWA. The National Institute for Occupational Safety and Health (NIOSH) has set a recommended exposure limit (REL) of 10 ppm, (15 mg/m³) ceiling (10 Minutes). It should be noted that a number of states in the US set their own PEL; in terms of US federal law, these may not be more permissive that the federal limit values.

Other National Standards

In the United Kingdom (UK) and European union (EU), the long-term occupational exposure limit (LTEL) for hydrogen sulfide is 7 mg/m³ (8-hour time TWA exposure reference period).

Conclusion: Occupational Standards

Many employers have made the strategic decision to base their corporate health and safety programs on conservative applicable recognized standards. Since ACGIH recommendations are frequently more conservative than OSHA PELs, many programs, especially the programs of multinational or prominent corporations, use the ACGIH TLV.

2.3.2 Community Standards and Guidelines

World Health Organisation (WHO, 2000)

The WHO provides a guideline for community exposure of 150 µg/m³ (0.1 ppm) averaged over 24h. The health end-point was eye irritation. To avoid odour annoyance, a 30-min average ambient air concentration not exceeding 7 µg/m³ (0.005 ppm) is recommended.

United States

No formal federal standards exist in the US. The US EPA does, however, have an inhalation reference concentration (RfC) for hydrogen sulfide, which is "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime." According to the EPA's on-line Integrated Risk Information System (IRIS) database, the current inhalation RfC for hydrogen sulfide is 2×10^{-3} mg/m³ or 2 µg/m³. Also, the individual states in the US have promulgated widely varying limit values (based on health impact or odour nuisance. It is worth noting that the California Office of Environmental Health Hazard Assessment (OEHHA) which follows a rigorous scientific process in determining Reference Exposure Levels (RELs) gives values of 42 µg/m³ for acute exposure (hourly average) and 10 µg/m³ for chronic exposure (lifetime). The health endpoint here is nausea and headache. The REL is the concentration level at or below which no adverse health effects are anticipated for a specified exposure duration. RELs are based on the most sensitive relevant adverse health effect reported in the medical and toxicological literature. RELs are designed to protect the most sensitive individuals in the population by the inclusion of margins of safety. As margins of safety are included in the determination of REL values, an exceedence of the REL does not necessarily signify that health impact will occur.

Iceland

In 2014 new standards will take effect in Iceland that lowers the current allowable level of H_2S from 5 exceedences per year of the 24 h guideline of 50 µg/m³ to no allowable exceedence. An annual guideline of 5 µg/m³ is given.

Conclusion: Health-Based Limit Values for Community Exposure

From the above survey, it is clear that the WHO community exposure guideline is not the most conservative value, especially in view of the fact that other health end points (in addition to the eye irritation used by the WHO) have been identified in the toxicological literature. It is recommended that OTTL regard the WHO value as the maximum allowable exposure, as it also is the Kenyan ambient air quality tolerance limit, but that the OEHHA and Iceland values are used as a target.

2.3.3 Odour Threshold Values

The following is taken verbatim from the OEHHA's document on REL values for H_2S (OEHHA 2013) as a recent summary of data on odour thresholds:

"Hydrogen sulfide has a strong unpleasant odor. The threshold for detection of this odor is low, but shows wide variation among individuals. A level of 7 µg/m³ (5 ppb), based on a 30 minute averaging time, was estimated by a Task Force of the International Programme on Chemical Safety (IPCS) (1981) to not produce odor nuisance in most situations"……

…."Amoore (1985) analyzed a large number of reports from the scientific literature and found that reported thresholds for detection were log-normally distributed, with a geometric mean of 10 µg/m³. Detection thresholds for individuals were reported to be log-normally distributed in the general population, with a geometric standard deviation of 4.0, i.e. 68% of the general population would be expected to have a detection threshold for hydrogen sulfide between 2.5 and 40 µg/m³ Sources of variation included age, sex, medical conditions, and smoking. Training and alertness of the subject in performing the test also affected the results. Amoore (1985) drew attention to the difference between a detection threshold under laboratory conditions, and the levels at which an odor could be recognized, or at which it was perceived as annoying. Analysis of various laboratory and sociological studies suggested that a level at which an odor could be recognized was typically a factor of three greater than the threshold for detection, while the level at which it was perceived as annoying was typically a factor of five greater than the threshold. Annoyance was characterized both in terms of esthetic or behavioral responses, and by physiological responses such as nausea and headache. He therefore predicted that, although at 10 µg/m³ (the proposed REL) 50% of the general population would be able to detect the odor of hydrogen sulfide under controlled conditions, only 5% would find it annoying at this level. At 50 µg/m³, 50% would find the odor annoying".

"On this basis, the proposed REL of 10 µg/m³ (7.17 ppb) is likely to be detectable by many people under ideal laboratory conditions, but it is unlikely to be recognized or found annoying by more than a few. It is therefore expected to provide reasonable protection from odor annoyance in practice. However, this consideration cannot be entirely dismissed due to the wide inter-individual variation in sensitivity to odors. Amoore (1985) also points out that many industrial operations generating hydrogen sulfide also generate organic thiol compounds with similar, but even more potent odors (e.g., methyl mercaptan, butyl mercaptan). Such compounds may in fact have detection thresholds as much as a hundred-fold lower than hydrogen

sulfide, so even minute quantities have a powerful impact on odor perception. Because of the concurrent emission of these contaminants, the incidence of odor complaints near hydrogen sulfide emitting sites correlated poorly with the levels of hydrogen sulfide measured in the affected areas".

For geothermal affected areas the common approach has been to use a value of 70 µg/m^3, which was based on the historic New Zealand Health Department guideline. This value of 70 µg/m^3 meets the Good Practice Guide for Assessing Odour in New Zealand recommendation whereby for low sensitivity receiving environments the ambient concentrations can be in the order of 5-10 odour units (equivalent to 5 -10 times the odour threshold) (Bay of Plenty Regional Council, 2012).

Conclusion: Odour Threshold Values

It would seem that the value of 70 µg/m^3 is a reasonably conservative number for the odour threshold in geothermal areas.

2.3.4 Summary of Assessment Criteria used in the Study

Table 1 provides a summary of the ambient assessment criteria used in the study.

Table 1: Summary of ambient air quality assessment criteria

Effect	Concentration (µg/m^3)	Concentration (ppm)	Averaging period
Occupational	1500 (ACGIH)	1	8 hour
Community Health	150 (WHO and Kenya) 50 (Iceland)	0.1 0.03	24 hour
	10 (OEHHA)	0.007	annual
Community Odour	70 (NZ) 7 (WHO)	0.05 0.005	1 hour 30 min

3 Description of the Receiving Environment

3.1 Air Quality Sensitive Receptors

An image of the site layout and AQSRs is given in Figure 3. AQSRs generally include places of residence and areas where members of the public may be affected by atmospheric emissions generated by industrial activities. The proposed geothermal power plant is located within the Menengai caldera, just north of Nakuru.

3.2 Atmospheric Dispersion Potential

Physical and meteorological mechanisms govern the dispersion, transformation, and eventual removal of pollutants from the atmosphere. The analysis of hourly average meteorological data is necessary to facilitate a comprehensive understanding of the dispersion potential of the site. Parameters useful in describing the dispersion and dilution potential of the site i.e. wind speed, wind direction, temperature and atmospheric stability, are subsequently discussed.

3.2.1 Topography and Land-use

The study area is located within the Menengai caldera. An analysis of topographical data indicated a slope of more than 1:10 from areas of operations to the nearest elevated point. Dispersion modelling guidance recommends the inclusion of topographical data in dispersion simulations in areas where the slope exceeds 1:10 (US EPA, 2004). The topography of the study area is shown in Figure 4.

3.2.2 Surface Wind Field

Wind roses comprise 16 spokes, which represent the directions from which winds blew during a specific period. The colours used in the wind roses below, reflect the different categories of wind speeds; the red area, for example, representing winds in between 6 and 10 m/s. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. The frequency with which calms occurred, i.e. periods during which the wind speed was below 1 m/s are also indicated.

The period wind rose (Figure 5) depicts the predominance of southerly winds with wind speeds of greater than 5 m/s. The day-time wind rose shows an increase in winds from the north-easterly sector and lower calms (3.7%), whereas the night-time wind rose shows an increase in the southerly winds and higher calms (7.9%).

The MM5 data used in the initial Quantum assessment depicted the predominance of south-south-easterly and north-north-westerly winds.

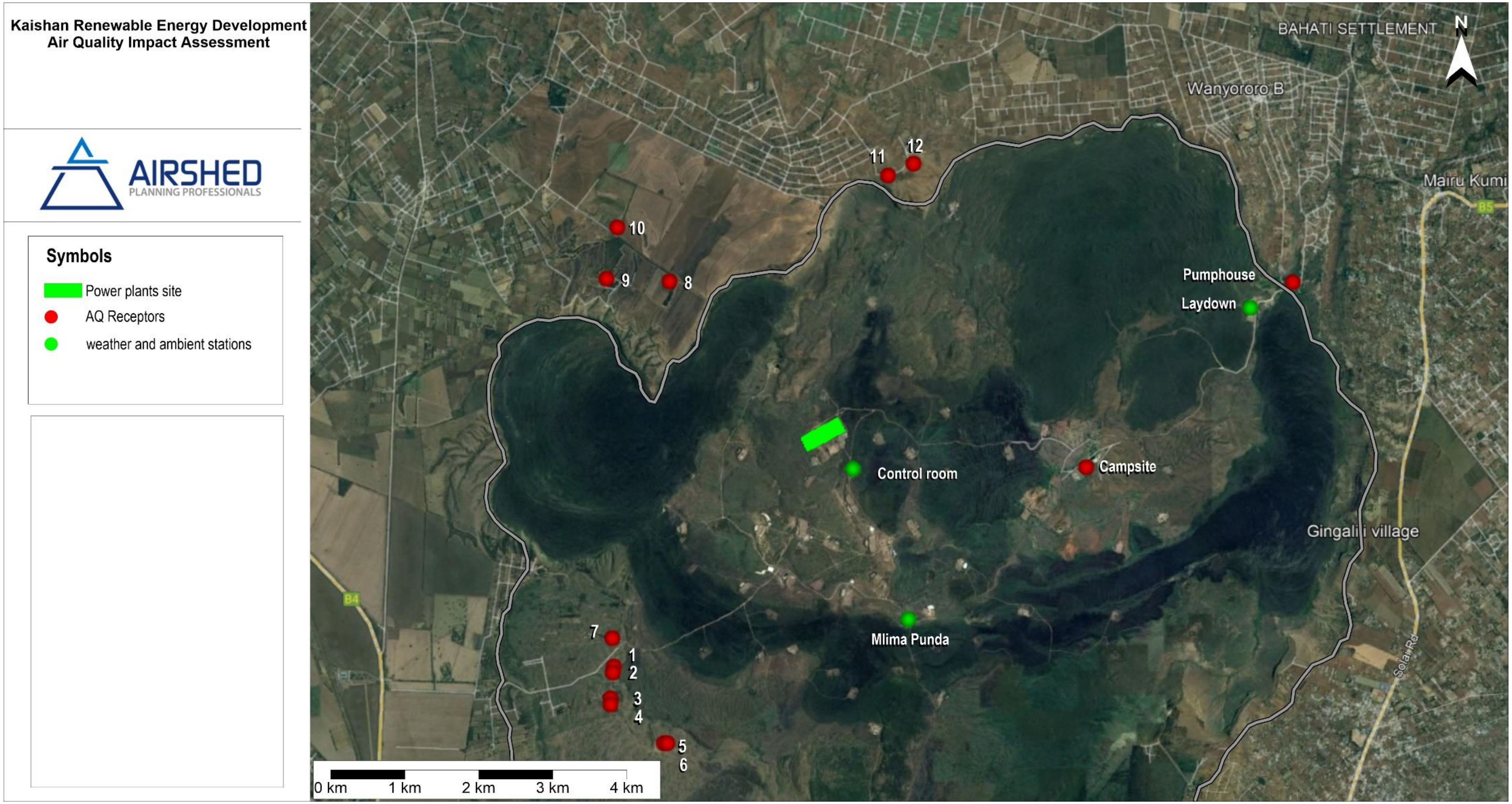

Figure 3: Study area, site layout and AQSRs

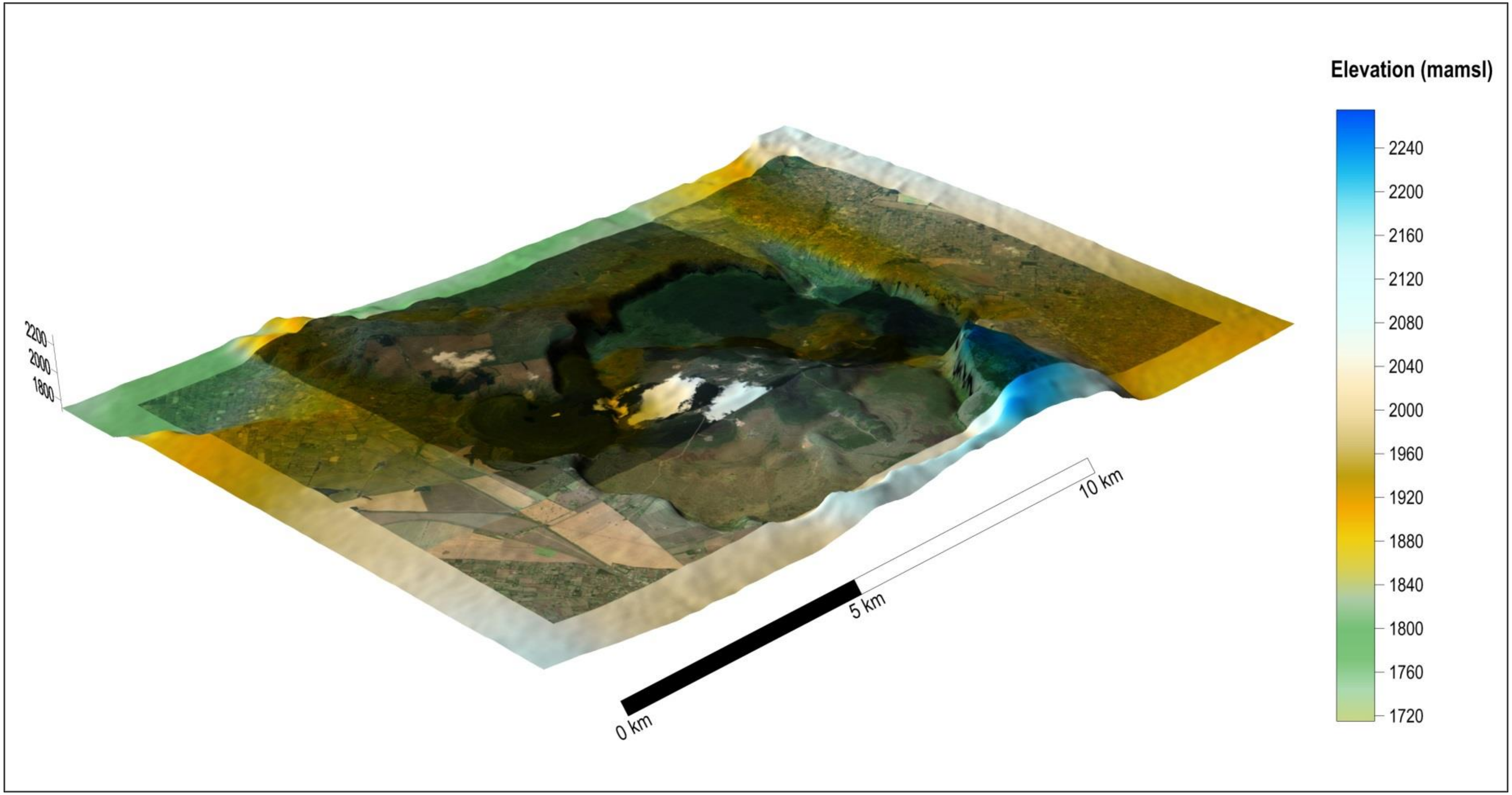

Figure 4: Topography of study area

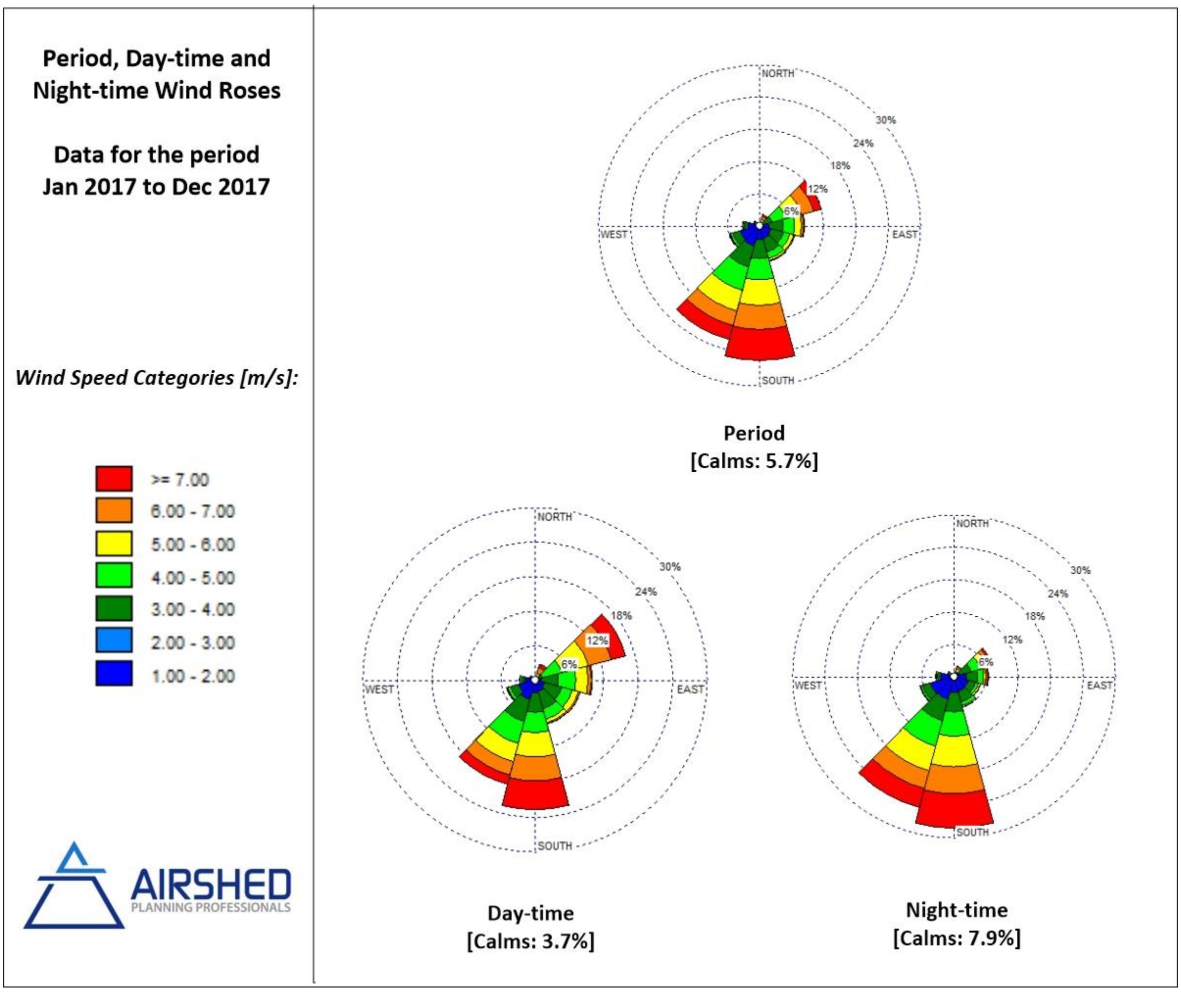

Figure 5: Period, day- and night-time wind roses (Control room data, 2017)

3.2.3 Temperature

Air temperature is important, both for determining the effect of plume buoyancy (the larger the temperature difference between the plume and the ambient air, the higher the plume is able to rise), and determining the development of the mixing and inversion layers. Minimum, mean and maximum temperatures for the project site for the period January 2017 – December 2017 are illustrated in Table 2.

Average temperatures range from 17°C in July and August to 21°C in March.

Table 2: Minimum, mean and maximum temperatures at project site (control room data) for the period Jan 2017 – Dec 2017

°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	-	12.2	13.0	12.4	12.0	12.3	12.1	12.3	12.7	12.1	10.7	10.3
Max	-	28.6	30.0	29.2	27.3	26.2	25.8	25.4	26.4	27.0	24.8	27.1
Average	-	19.6	20.7	19.3	17.7	18.2	16.8	16.9	17.1	17.6	16.6	18.2

3.2.4 Rainfall

Precipitation is important to air pollution studies since it represents an effective removal mechanism for atmospheric pollutants and inhibits dust generation potentials. Monthly rainfall for the project site (February 2017– December 2017) is given in Figure 6. Total annual rainfall for 2017 is in the range of 1289 mm.

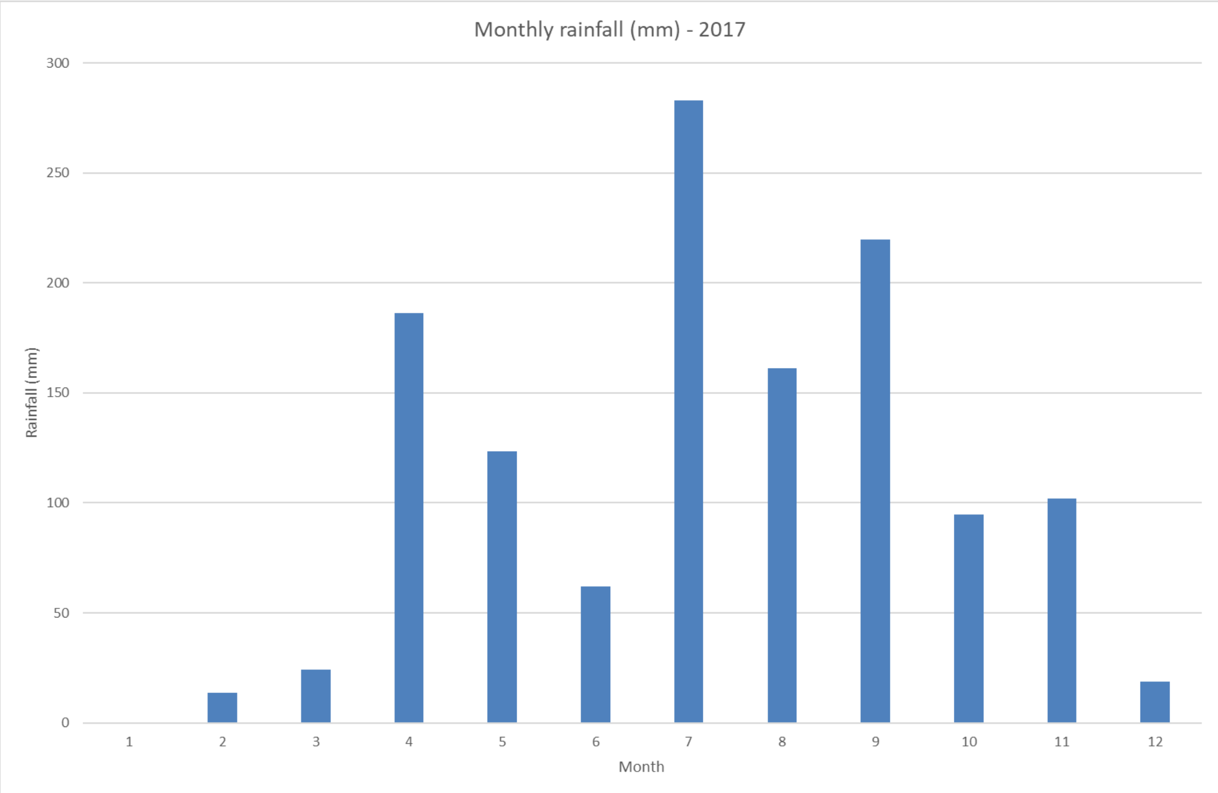

Figure 6: Monthly precipitation at the project site (control room data for the period Jan 2017 – Dec 2017)

3.3 Pre-Development Ambient Air Pollutant Concentrations

The proposed geothermal power plant is located in an area affected by natural sources of atmospheric emissions, including steam, carbon dioxide, and H_2S, via natural geothermal features such as vents and fumaroles and in some areas the smell of hydrogen sulfide is noticeable.

Potential atmospheric emissions from the project are discussed in section 4; the only air pollutant considered to be of concern at this stage is H_2S. Monitoring for H_2S levels in the ambient air from existing geothermal features (wells within the caldera) is conducted by the Geothermal Development Company (GDC) of Kenya. The results of this campaign are given in Figure 7 and Figure 8. Monitoring results were available on a monthly basis for the time period 2015 to April 2019. To summarise the data, the results were averaged per year.

The concentrations of H_2S were monitored and it was found that they were often higher downwind of the wells. The wells that were discharging also show elevated levels (e.g. it was recorded that during 2016, wells 1, 9 12 and 13 were discharging). At most of these monitored wells, the odour threshold (0.00046 ppm-0.002 ppm or 0.76-3.21 µg/m^3) is frequently exceeded, as well as the ACGIH TLV for H_2S which is set at 1 ppm (1 500 µg/m^3) for an eight hour exposure.

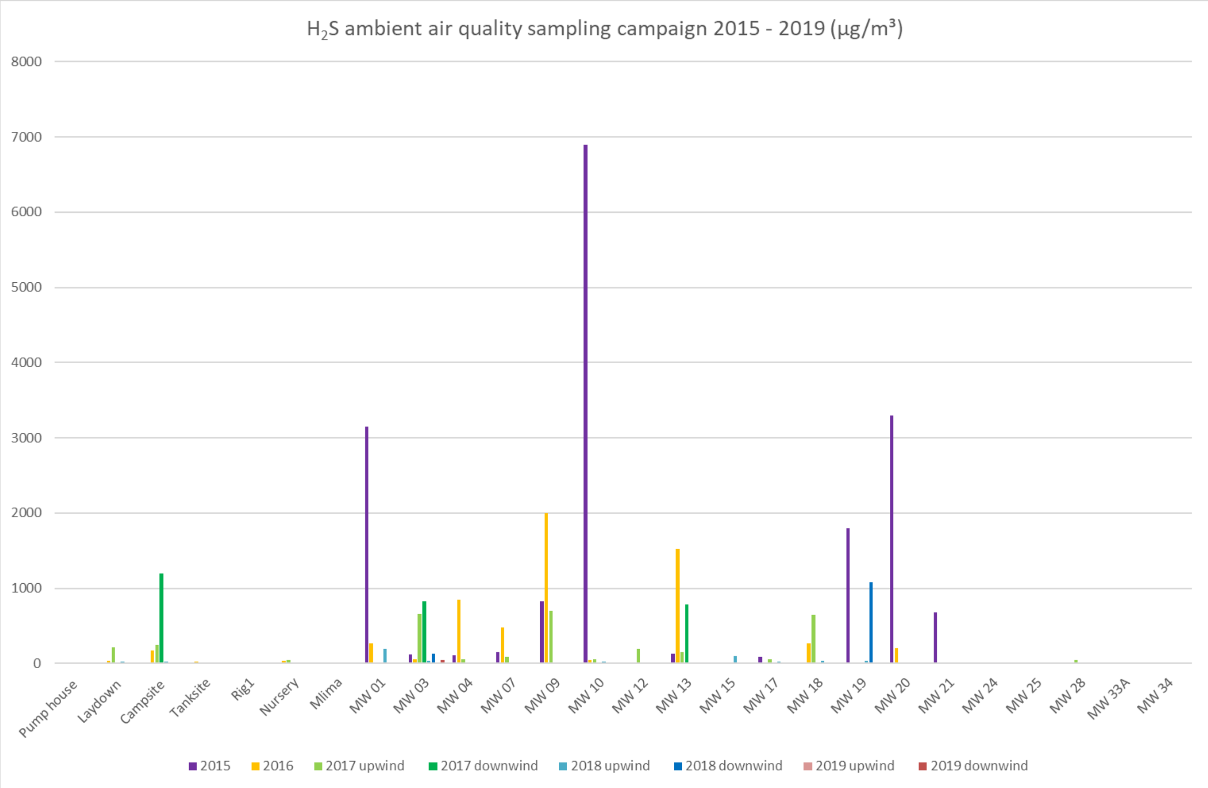

Figure 7: Summary of pre-development ambient air quality sampling campaign results

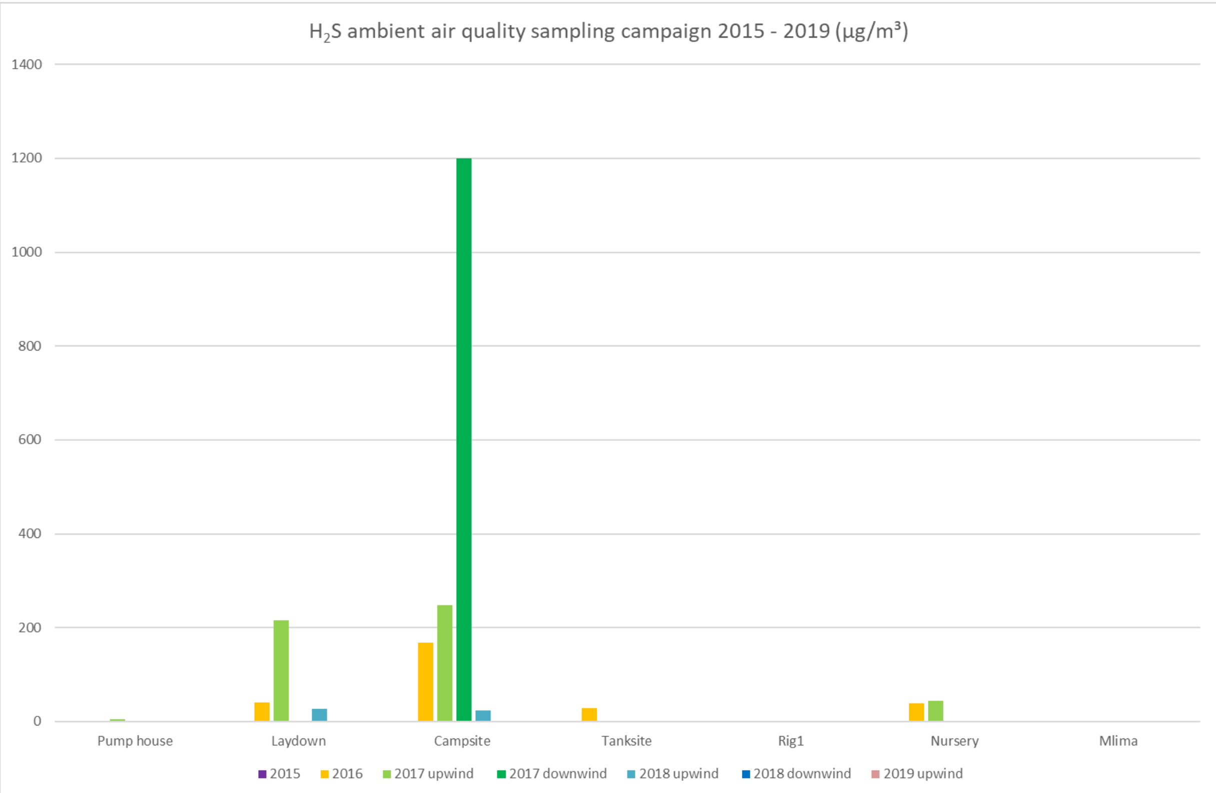

Figure 8: Summary of pre-development ambient air quality sampling campaign results at the AQSRs

4 Impact of Enterprise on the Receiving Environment

4.1 Atmospheric Emissions

The establishment of a comprehensive emission inventory formed the basis for the assessment of the air quality impacts from the project's operations on the receiving environment.

4.1.1 Kaishan

A summary of emissions quantified for Kaishan and source input parameters are provided in Table 3.

Table 3: Estimated stack parameters and emission rates for the Kaishan plant

Equipment and arrangement options	Stack parameters				Stack emissions		
	Height (m)	Diameter (m)	Velocity (m/s)	Temp (°C)	H_2S per stack (g/s)	H_2S total (g/s)	H_2S total (tpa)
Assuming multiple (34) vents	10.3	4.5	4.8	52	3.29	112	3467

4.1.2 Quantum

A summary of emissions quantified for Quantum was obtained from the study done in 2015 (Petzer & Bornman, 2015) and source input parameters are provided in Table 4.

Table 4: Estimated stack parameters and emission rates for the Quantum plant

Equipment and arrangement options	Stack parameters				Stack emissions		
	Height (m)	Diameter (m)	Velocity (m/s)	Temp (°C)	H_2S per stack (g/s)	H_2S total (g/s)	H_2S total (tpa)
Assuming single stack	30	0.4	13	33	76	76	2397

4.1.3 Sosian

A summary of emissions quantified for Sosian was obtained from the study done in 2019 (Petzer, 2019) and source input parameters are provided in Table 5.

Table 5: Estimated stack parameters and emission rates for the Sosian plant

Equipment and arrangement options	Stack parameters				Stack emissions		
	Height (m)	Diameter (m)	Velocity (m/s)	Temp (°C)	H_2S per stack (g/s)	H_2S total (g/s)	H_2S total (tpa)
Assuming multiple (40) vents	7	2.2	15.1	52	2.9	117.1	3693

4.2 Atmospheric Dispersion Modelling

The assessment of the impact of the project's operations on the environment is discussed in this section. To assess impact on human health and the environment the following important aspects need to be considered:

- The criteria against which impacts are assessed (Section 2);
- The potential of the atmosphere to disperse and dilute pollutants emitted by the project (Section 3.2); and
- The methodology followed in determining ambient pollutant concentrations (Section 1.2.4)

The impact of operations on the atmospheric environment was determined through the simulation ambient pollutant concentrations.

Table 6 shows the scenarios included in the dispersion modelling results.).

Table 6: Scenarios considered for the three IPP

Scenario	Equipment and arrangement options	IPP and Emission Point		
		Kaishan	Quantum	Sosian
1	Assuming Quantum single stack and Kaishan and Sosian dispersal from multiple vents	Multiple vents	Single stack	Multiple vents
2	Incremental impact from OTTL dispersal from 4 cooling tower fans	Multiple vents	-	-

Dispersion models simulate ambient pollutant concentrations as a function of source configurations, emission strengths and meteorological characteristics, thus providing a useful tool to ascertain the spatial and temporal patterns in the ground level concentrations arising from the emissions of various sources. Increasing reliance has been placed on concentration estimates from models as the primary basis for environmental and health impact assessments, risk assessments and emission control requirements. It is therefore important to carefully select a dispersion model for the purpose.

4.2.1 Dispersion Model Selection

Version 5 of ADMS was used in the study (Section 1.2.4).

4.2.2 Meteorological Requirements

For the purpose of the current study use was made of hourly control room data for the period 2017 (Section 3.2).

4.2.3 Source Data Requirements

The ADMS model is able to model point, jet, area, line and volume sources. Stack and cooling tower fans were modelled as point sources.

4.2.4 Modelling Domain

The dispersion of pollutants expected to arise from proposed activities was modelled for an area covering 15 km (east-west) by 10 km (north-south). The area was divided into a grid matrix with a resolution of 200 m, with the geothermal power plants located centrally. The nearest town and farmsteads were included as AQSR (Figure 3). ADMS calculates ground-level (1.5 m above ground level) concentrations at each grid and discrete receptor point. Topography was included in dispersion simulations.

4.2.5 Presentation of Results

Dispersion modelling was undertaken to determine highest hourly, 8 hourly, highest daily and annual average ground level concentrations. Averaging periods were selected to facilitate the comparison of simulated pollutant concentrations to relevant ambient air quality, inhalation health criteria and odour thresholds.

Results are primarily provided in tabular form as discrete values simulated at specific AQSR receptor locations. Selective use is also made of isopleths to present areas of exceedance of assessment criteria. Ground level concentration isopleths presented in this section depict interpolated values from the concentrations simulated by ADMS for each of the receptor grid points specified.

It should be noted that ambient air quality criteria apply to areas where the Occupational Health and Safety regulations do not apply, thus outside the property or lease area. Ambient air quality criteria are therefore not occupational health indicators but applicable to areas where the general public has access i.e. off-site.

The potential impact on human health as a result of H_2S emissions from proposed operations are discussed in Section 4.3. The occupational impact is discussed in Section 4.4. Section 4.5 discusses the odour impact.

4.3 Screening of Simulated Human Health Impacts from H_2S

For Scenario 1, with Quantum emitting from a single stack and Kaishan and Sosian emitting from multiple vents, simulated 24-hour ambient H_2S concentrations exceed the Iceland guideline of 50 µg/m³ at some of the AQSRs, but not the Kenyan Tolerance Limit of 150 µg/m³ with 3 allowable exceedences or WHO daily guideline value of 150 µg/m³ (Table 7). Simulated annual average ambient H_2S concentrations exceed the OEHHA screening level for chronic exposure (10 µg/m³) at some of the AQSRs. Isopleth plots for are shown in Figure 9 to Figure 11.

Table 7: Simulated ambient H_2S concentrations during the operational phase for Scenario 1

AQSRs		Simulated Ambient H_2S Concentrations During the Operational Phase (1)		
Num-ber	Description	4th Highest 24-hour Ground Level Conc. (µg/m³)	2nd Highest 24-hour Ground Level Conc. (µg/m³)	Annual Ave. Ground Level Conc. (µg/m³)
1	Structure 1	40	47	4.7
2	Structure 2	39	46	4.3
3	Structure 3	34	38	3.0
4	Structure 4	33	37	2.7
5	Structure 5	8	13	0.4
6	Structure 6	7	12	0.3
7	Structure 7	49	**58**	7.0
8	Marigo area 1	30	36	6.7
9	Marigo area 2	39	44	8.5
10	Marigo area 3	23	29	5.2
11	Rigogo area 1	112	**115**	**36.9**
12	Rigogo area 2	99	**122**	**35.5**
	GDC Campsite	33	34	3.0
	Pumphouse and nursery	12	22	1.9
	Mlima Punda	2	4	0.04
	Laydown	14	17	2.2
	Control room	53	**58**	3.3
	Criteria	**150 (Kenya)** **Kenya allows for 3 exceedences per year**	**50 (Iceland)** **150 (WHO)**	**10 (OEHHA)**

(1) Values in bold indicate exceedences of guidelines or standards

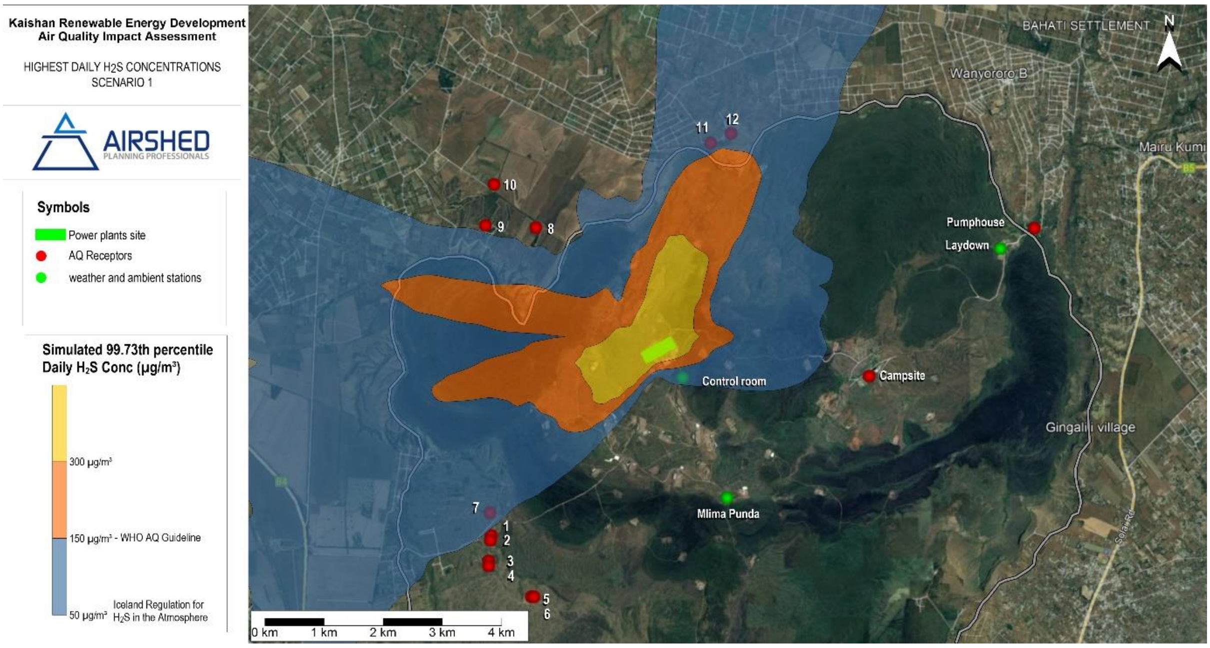

Figure 9: 99.73th percentile of daily ground level H_2S concentrations – Scenario 1

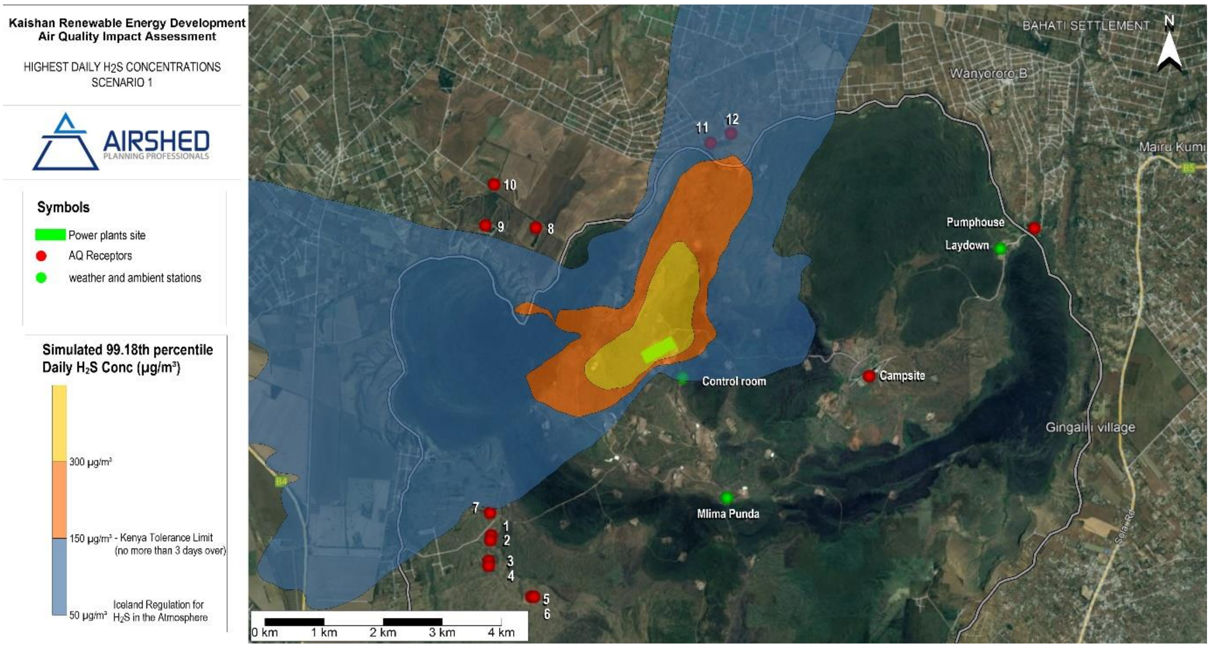

Figure 10: 99.2th percentile of daily ground level H_2S concentrations – Scenario 1

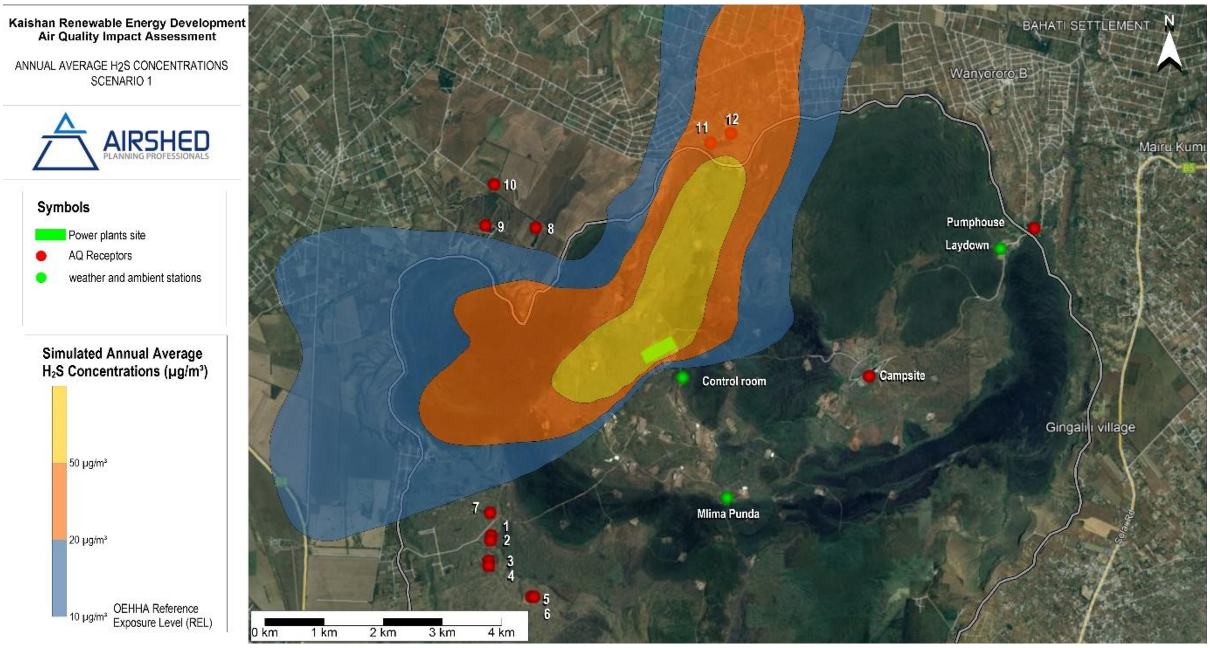

Figure 11: Annual average ground level H_2S concentrations – Scenario 1

For Scenario 2, showing Kaishan's incremental impact, simulated 24-hour ambient H_2S concentrations do not exceed the Iceland guideline of 50 µg/m³ or the Kenyan Tolerance Limit of 150 µg/m³ with 3 allowable exceedences or the WHO daily guideline value of 150 µg/m³ at any of the AQSRs. Simulated annual average ambient H_2S concentrations exceed the OEHHA screening level for chronic exposure (10 µg/m³) at two of the AQSRs (Table 8). Isopleth plots for are shown in Figure 12 to Figure 14.

Table 8: Simulated ambient H_2S concentrations during the operational phase for Scenario 2

AQSRs		Simulated Ambient H_2S Concentrations During the Operational Phase (1)		
Number	Description	4th Highest 24-hour Ground Level Conc. (µg/m³)	2nd Highest 24-hour Ground Level Conc. (µg/m³)	Annual Ave. Ground Level Conc. (µg/m³)
1	Structure 1	13	16	1.6
2	Structure 2	12	15	1.5
3	Structure 3	11	12	1.0
4	Structure 4	10	11	0.9
5	Structure 5	2	3	0.1
6	Structure 6	2	3	0.1
7	Structure 7	16	20	2.5
8	Marigo area 1	11	13	2.1
9	Marigo area 2	11	16	2.0
10	Marigo area 3	10	11	1.6
11	Rigogo area 1	37	41	**13.4**
12	Rigogo area 2	40	45	**12.9**
	GDC Campsite	11	16	1.0
	Pumphouse and nursery	4	8	0.6

AQSRs		Simulated Ambient H_2S Concentrations During the Operational Phase (1)		
Number	**Description**	**4th Highest 24-hour Ground Level Conc. (µg/m³)**	**2nd Highest 24-hour Ground Level Conc. (µg/m³)**	**Annual Ave. Ground Level Conc. (µg/m³)**
	Mlima Punda	1	2	0.02
	Laydown	5	5	0.7
	Control room	24	34	2.0
	Criteria	**150 (Kenya)** **Kenya allows for 3 exceedences per year**	**50 (Iceland)** **150 (WHO)**	**10 (OEHHA)**

(1) Values in bold indicate exceedences of guidelines or standards

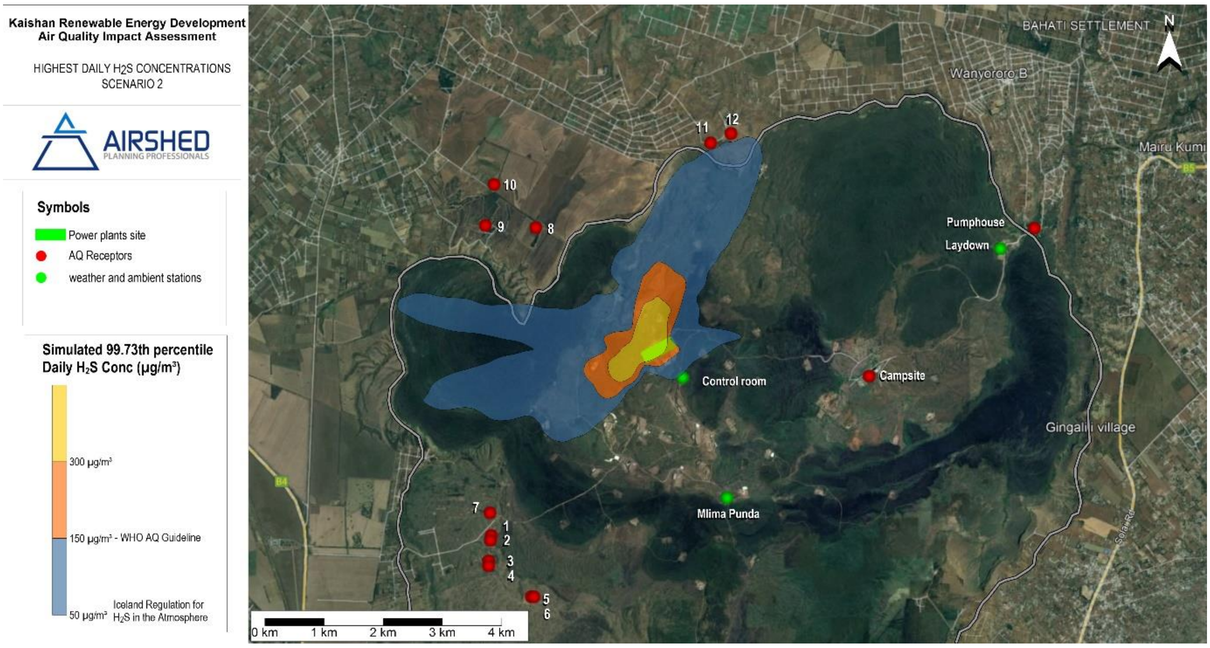

Figure 12: Highest daily ground level H_2S concentrations – Scenario 2

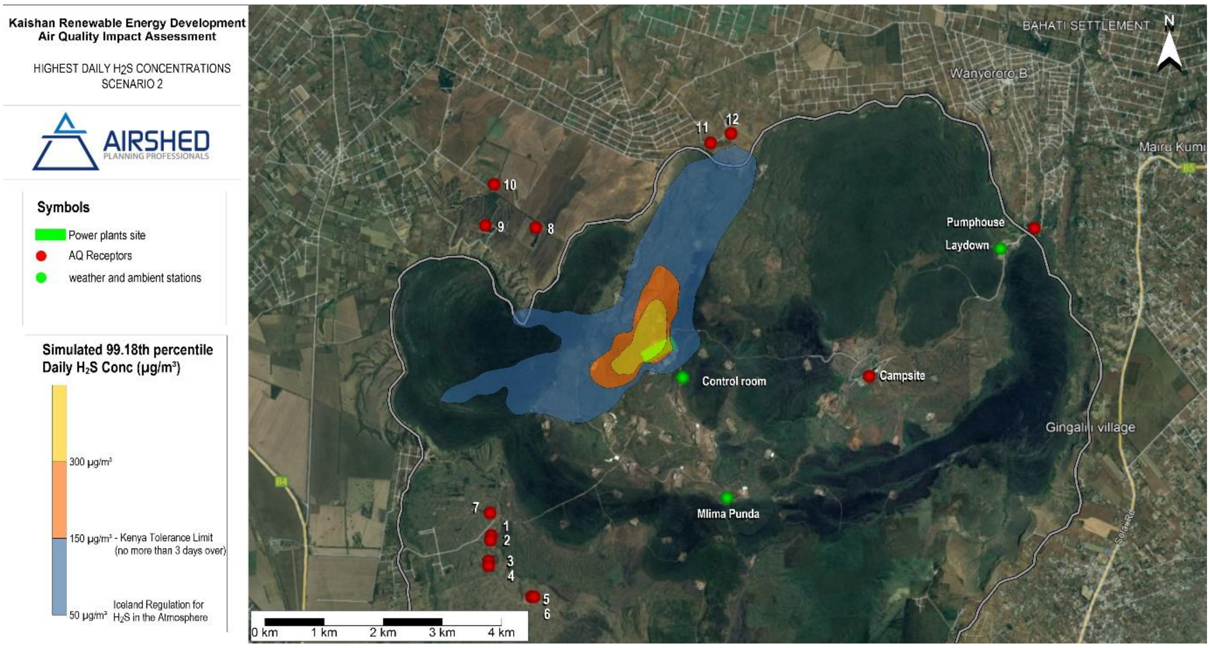

Figure 13: 99.2th percentile of daily ground level H2S concentrations – Scenario 2

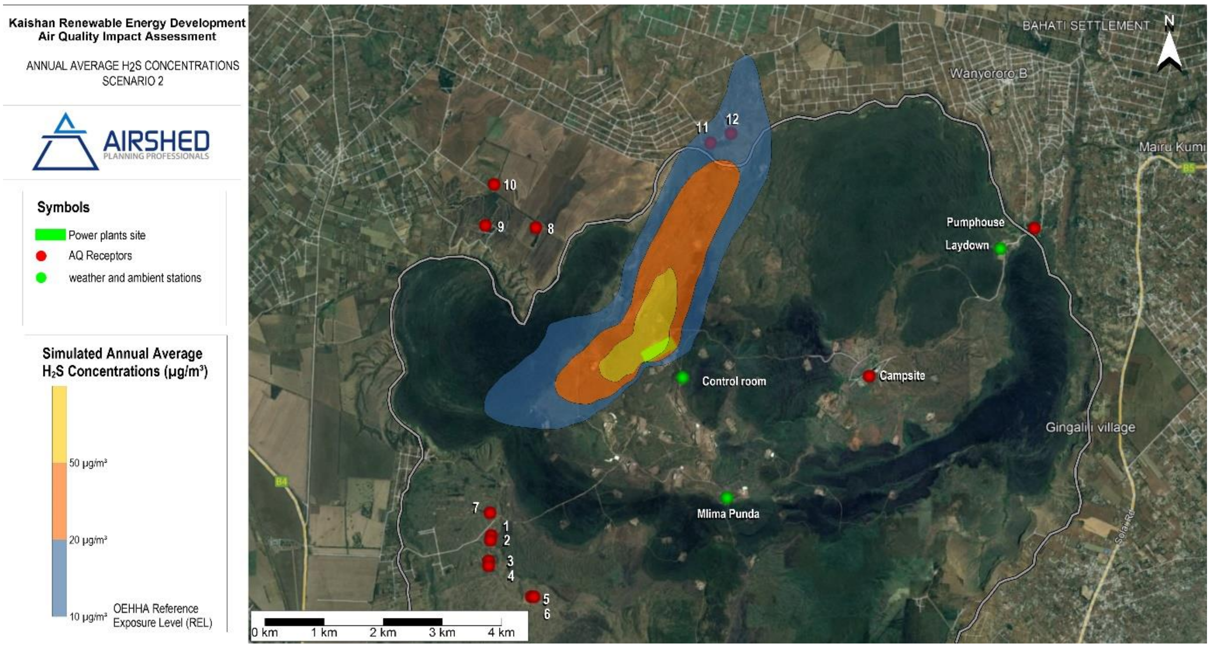

Figure 14: Annual average ground level H2S concentrations – Scenario 2

4.4 Analysis of H_2S Emissions Occupational Impact

To assess occupational health only the plant boundary is considered. For Scenario 1, the ACGIH TLV of 1ppm (1500 µg/m³) is exceeded both on-site as well as ~300 m from the site boundary (Figure 15). For Scenario 2, the TLV is exceeded just off-site for a small area (Figure 16). None of the scenarios exceed the WHO lowest observable adverse effect level (LOAEL) of 15 mg/m³ (15 000 µg/m³) or 10 ppm.

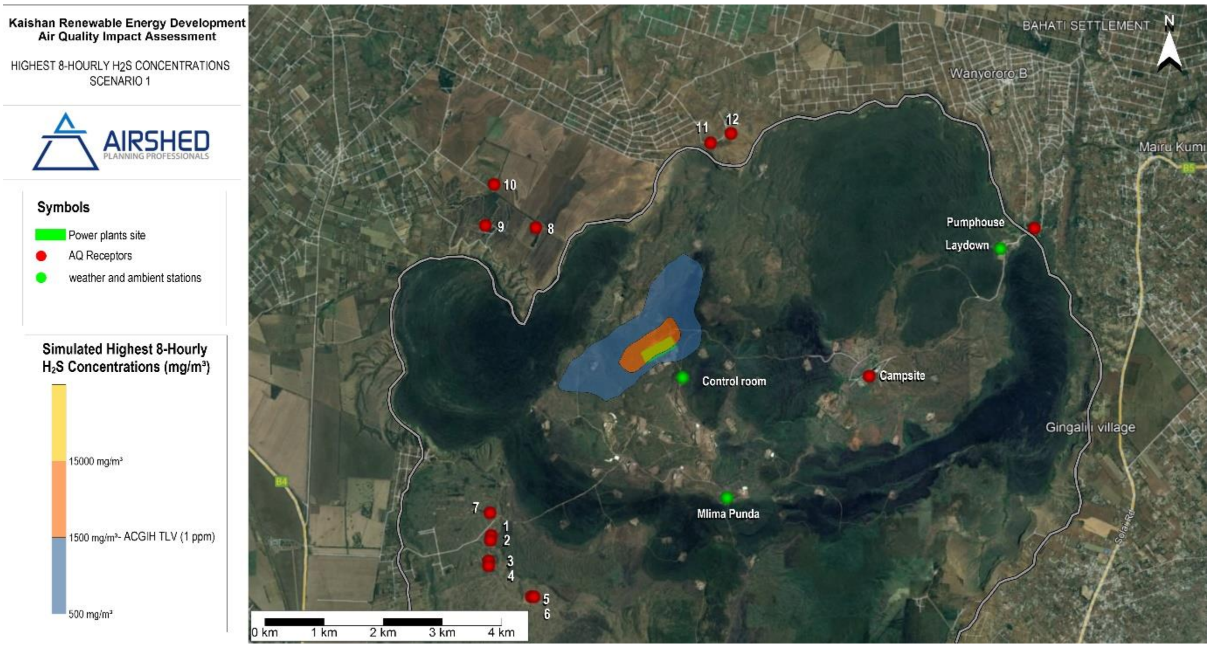

Figure 15: Highest 8-hr ground level H_2S concentrations – Scenario 1

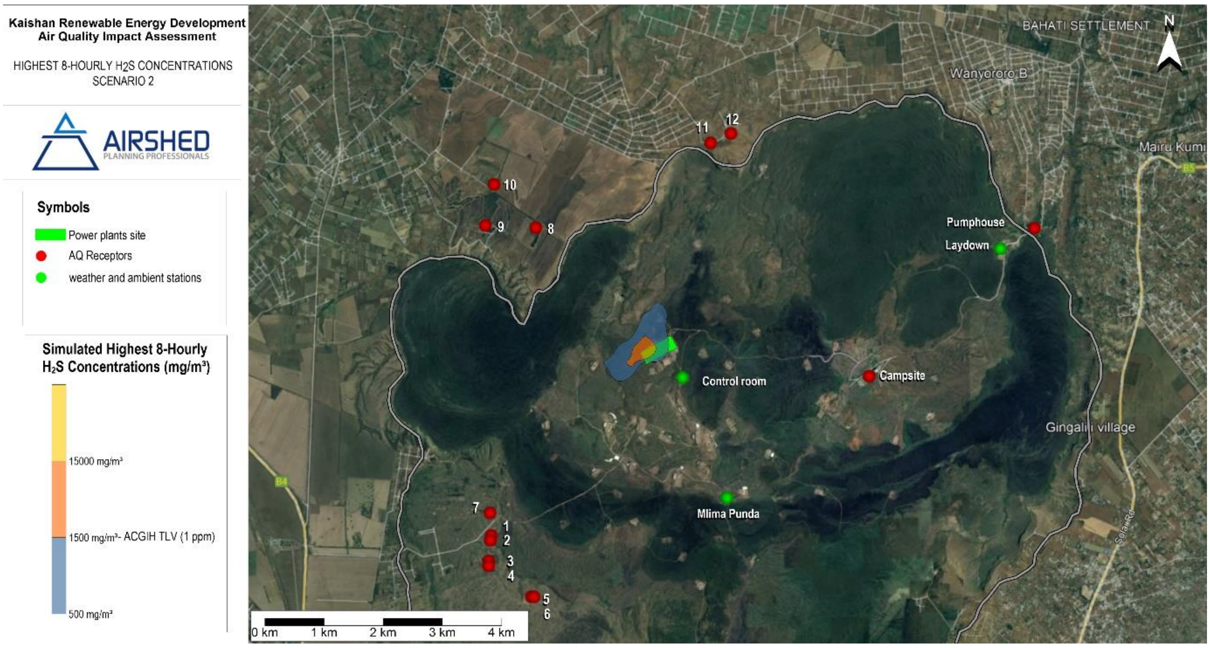

Figure 16: Highest 8-hr ground level H_2S concentrations – Scenario 2

4.5 Simulated Odour Impacts from H_2S

The results of the modelling suggest that a H_2S odour impact is possible and it has the potential under certain meteorological conditions to be regarded as a nuisance (offensive or objectionable) (Figure 17 and Figure 18). For Scenario 2, the New Zealand guideline value (70 µg/m³ for geothermal areas) is only exceeded at two of the selected sensitive receptors (Table 9).

Table 9: Simulated 98th percentile hourly H_2S concentrations during the operational phase for Scenario 1 and 2

AQSRs		98th percentile 1-hour Ground Level Conc. (µg/m³) (1)	
Number	Description	Scenario 1	Scenario 2
1	Structure 1	**74**	26
2	Structure 2	69	24
3	Structure 3	48	16
4	Structure 4	43	15
5	Structure 5	3	1
6	Structure 6	3	1
7	Structure 7	**105**	37
8	Marigo area 1	**85**	29
9	Marigo area 2	**103**	25
10	Marigo area 3	67	20
11	Rigogo area 1	**254**	**92**
12	Rigogo area 2	**242**	**93**
	GDC Campsite	51	15
	Pumphouse and nursery	33	9
	Mlima Punda	0	0
	Laydown	33	10
	Control room	6	6
Criteria		**70 (New Zealand)**	

(1) Values in bold indicate exceedences of guidelines or standards

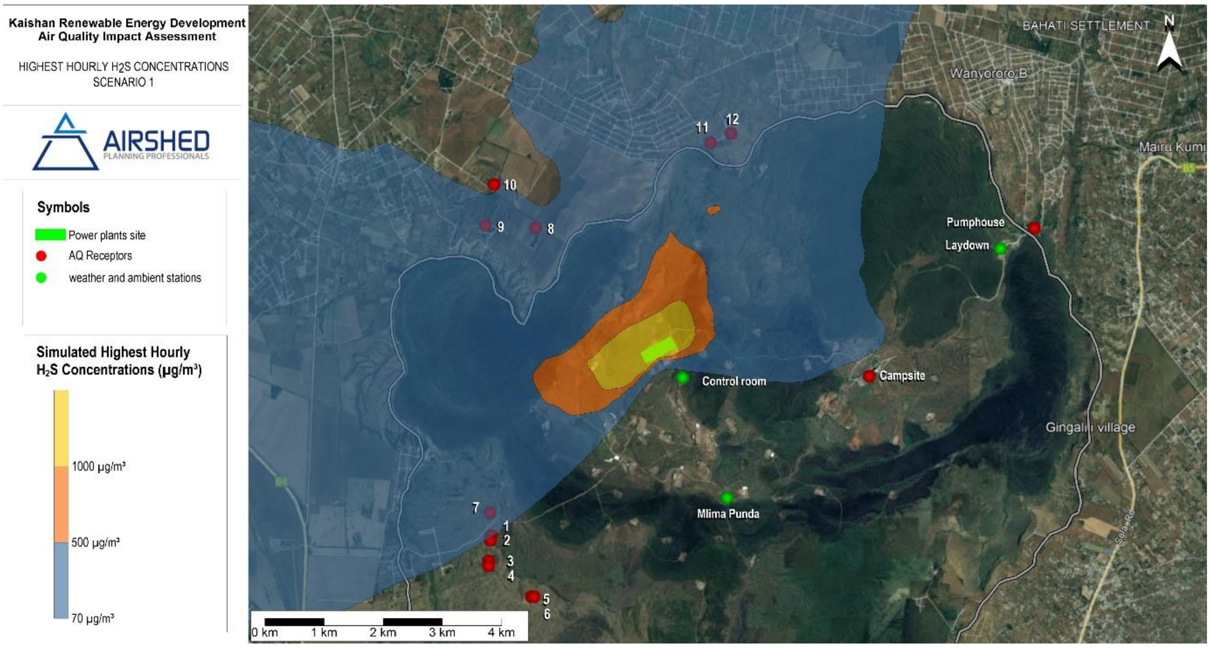

Figure 17: Highest hourly ground level H_2S concentrations – Scenario 1

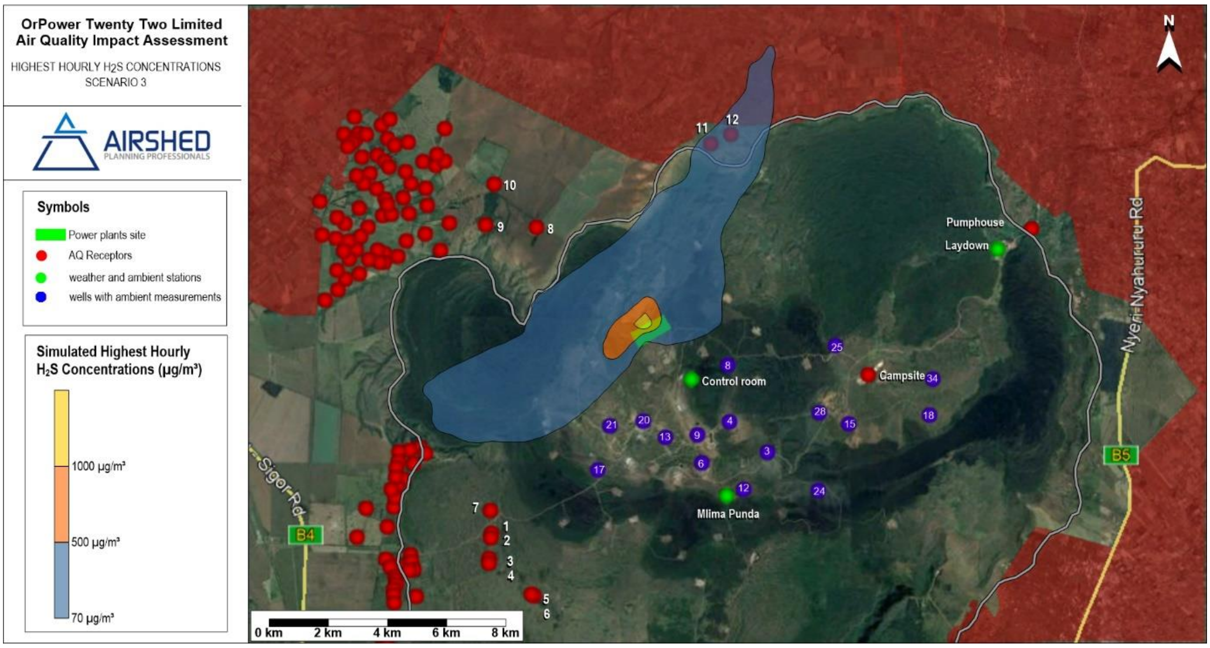

Figure 18: Highest hourly ground level H_2S concentrations – Scenario 2

5 MAIN FINDINGS

An air quality impact assessment was conducted for the operational phase activities planned for the proposed Menengai Geothermal Power Plant. The main objective of this study was to quantify the extent to which ambient pollutant levels will increase as a result of the project. This section summarises the main findings of the assessment.

- Receiving environment:
  - The wind direction for the area is predominantly from the south and northeast. Long term air quality impacts are therefore expected to the north and southwest of the proposed operations.
  - Ambient air quality monitoring conducted at the wells by the Geothermal Development Company (GDC), from 2016 to 2019 indicated ambient air pollutant levels that exceed the odour threshold as well as the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) of 1 ppm.
  - Several AQSRs are situated within the vicinity of the proposed power plant (several homesteads in the caldera, 3.5 km southwest of the plant, and areas outside of caldera 2 km northwest of the plant, Marigo, and 2.5 km north-northeast of the plant, Rigogo).
- Impact of the proposed Menengai Geothermal Power Plant:
  - Health Impact:
    - For Scenario 1, with Quantum emitting from a single stack and Kaishan and Sosian emitting from multiple vents, simulated 24-hour ambient H_2S concentrations exceed the Iceland guideline of 50 µg/m³ at some of the AQSRs. However, the Kenyan Tolerance Limit and World Health Organization (WHO) daily guideline value of 150 µg/m³ is not exceeded at any of the AQSRs. Simulated annual average ambient H_2S concentrations exceed the California Office of Environmental Health Hazard Assessment (OEHHA) screening level for chronic exposure (10 µg/m³) at some of the AQSRs in the Rigogo area.
    - For Scenario 2, Kaishan's incremental impact, simulated 24-hour ambient H_2S concentrations do not exceed the Iceland guideline of 50 µg/m³ or Kenyan Tolerance Limit and the WHO daily guideline value of 150 µg/m³ at any of the AQSRs. Simulated annual average ambient H_2S concentrations exceed the OEHHA screening level for chronic exposure (10 µg/m³) at the Rigogo area.
  - Occupational Impact:
    - For Scenario 1, the ACGIH TLV of 1ppm (1500 µg/m³) is exceeded both on-site as well as ~ 300 m from the site boundary. For Scenario 2, the ACGIH TLV of 1ppm (1500 µg/m³) is exceeded for a very small area just off-site. None of the scenarios exceed the WHO lowest observable adverse effect level (LOAEL) of 15 mg/m³ (15 000 µg/m³) or 10 ppm.
  - Odour Impact:
    - The results of the modelling suggest it is possible that there will be a H_2S odour impact at the AQSRs.

To ensure the lowest possible impact on AQSRs and the environment it is recommended that an air quality management plan should be adopted. This includes:

- The mitigation of sources of emission;
- The management of associated air quality impacts; and
- Ambient air quality monitoring.

6 RECOMMENDATIONS

Based on the findings of the impact assessment, the following mitigation, management and monitoring recommendations are made.

It is recommended that the source parameters used in the dispersion modelling be confirmed, as these will influence the simulated ground level concentrations.

It is recommended that once the final design parameters are available for each IPP, they be compared to the simulated parameters, and if significantly different dispersion modelling be redone to reassess the impact.

6.1 Possible Mitigation Methods

Some potential mitigation measures which could be applied during operation to reduce impacts on air quality include (IFC, 2007):

- Total or partial re-injection of gases with geothermal fluids;
- Abatement systems to remove hydrogen sulfide emissions from non-condensable gases. Examples of hydrogen sulfide controls can include wet or dry scrubber systems or a liquid phase reduction / oxidation system.

Iceland

In 2014 stricter standards took effect in Iceland that lower the allowable levels of atmospheric H_2S. The H_2S levels stipulated in the regulations are significantly lower than the current WHO guidelines and require the Icelandic geothermal industry to take action to reduce its H_2S emissions. To tackle this challenge, three Icelandic energy companies that all produce power from high temperature geothermal fields, Reykjavik Energy, Landsvirkjun and HS Orka, joined forces to develop the best abatement solution. Hydrogen sulfide is a known pollutant in a number of industries and is formed where sulphur reacts under anaerobic conditions such as in oil reservoirs and geothermal systems. The petroleum industry has used abatement technologies for H_2S mitigation for a long time. Commonly the H_2S is oxidized by burning it in the atmosphere, forming SO_2 or by oxidizing it to elemental sulphur. The methods of producing elemental sulphur, such as by the Claus method where H_2S is partly burnt followed by catalytic oxidation over to elemental sulphur, or the liquid redox method where H_2S is oxidized with metals such as iron or vanadium, results in formation of solid sulphur. In most cases sulphur is a commodity and can be utilized for a wide industrial application such as production of sulphuric acid. However due to the remote location of Iceland and absence of industries that use sulphur, the specific conditions in Iceland lead to further studies on possible mitigation methods. It was therefore decided to build on research and development of reinjection methods for CO_2 at Reykjavik Energy to develop an abatement method called SulFix. The aim of the SulFix project is to develop a sustainable and environmentally friendly H_2S abatement method with lower operation costs than commercially available abatement options. The process dissolves H_2S in condensate water and injects it back into the high temperature geothermal reservoir. Once injected, water-rock reactions taking place in the high temperature geothermal reservoir will mineralize the H_2S (Juliusson, et al., 2015).

6.2 Performance Indicators

Key performance indicators against which progress of implemented mitigation and management measures may be assessed form the basis for all effective environmental management practices. In the definition of key performance indicators careful attention is usually paid to ensure that progress towards their achievement is measurable, and that the targets set are achievable given available technology and experience.

Performance indicators are usually selected to reflect both the source of the emission directly (source monitoring) and the impact on the receiving environment (ambient air quality monitoring). Ensuring that emissions are below a certain mg/Nm³ represents an example of a source-based indicator, whereas maintaining off-site concentrations to below e.g. 50 µg/m³ represents an impact- or receptor-based performance indicator.

Source monitoring can be challenging. The focus is therefore rather on receptor-based performance indicators i.e. compliance with ambient air quality standards and/or guidelines. It is recommended that the criteria listed in Table 1 be adopted by Menengai geothermal power plant as receptor-based objectives.

6.2.1 Ambient Air Quality Monitoring

IFC (2007) recommends the following planning process and precautions as a result of the potential for H_2S exposure to the community:

- Siting of potential significant emissions sources with consideration of hydrogen sulfide gas exposure to nearby communities (considering key environmental factors such as proximity, morphology and prevailing wind directions);
- Installation of a hydrogen sulfide gas monitoring network;
- Continuous operation of the hydrogen sulfide gas monitoring systems to facilitate early detection and warning; and
- Emergency planning involving community input to allow for effective response to monitoring system warnings.

6.3 Record-keeping, Environmental Reporting and Community Liaison

6.3.1 Periodic Inspections and Audits

Periodic inspections and external audits are essential for progress measurement, evaluation and reporting purposes. It is recommended that site inspections and progress reporting be undertaken at regular intervals (at least quarterly), with annual environmental audits being conducted. Annual environmental audits should be continued at least until closure. Results from site inspections and monitoring efforts should be combined to determine progress against source- and receptor-based performance indicators. Progress should be reported to all interested and affected parties, including authorities and persons affected by pollution.

The criteria to be taken into account in the inspections and audits must be made transparent by way of minimum requirement checklists included in the management plan. Corrective action or the implementation of contingency measures must be proposed to the stakeholder forum in the event that progress towards targets is indicated by the quarterly/annual reviews to be unsatisfactory.

6.3.2 Liaison Strategy for Communication with I&APs

Stakeholder forums provide possibly the most effective mechanisms for information dissemination and consultation. Management plans should stipulate specific intervals at which forums will be held, and provide information on how people will be notified of such meetings.

6.3.3 Financial Provision

The budget should provide a clear indication of the capital and annual maintenance costs associated with monitoring plans. Costs related to inspections, audits, environmental reporting and I&AP liaison should also be indicated where applicable. The financial plan should be audited by an independent consultant, with reviews conducted on an annual basis.

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