Air Quality Assessment For Development Options At Olkaria Geothermal Field In Kenya

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ABSTRACT

Utilisation of geothermal energy for direct and indirect uses is inexorably gaining momentum in many parts of the world endowed with the resource. Kenya has plentiful geothermal resources estimated to be over 10,000 MW that have not been exploited to full potential. The power demand in Kenya exceeds the supply and has been growing at 8% per annum. Consequently, the country has developed an ambitious strategy, and intends to develop 5,000 MW by the year 2017, which is about 3 times the existing capacity. Out of this, 700 MW is expected to be generated from Olkaria Geothermal Field.

Olkaria I & II Geothermal Power Stations are located within a national park, at close proximity to a commercial flower farm and ~5 km South of Lake Naivasha which is a Ramsar site. Hence there is need to consider the cumulative effects of hydrogen sulphide gas emitted from the power plants. This study therefore assesses the potential air quality impacts associated with the proposed development options at Olkaria Geothermal Field. Calmet and Calpuff dispersion models, which are recognised by the US EPA, have been employed to assess the air quality associated with emissions from the proposed geothermal expansion at Olkaria. Three different emission scenarios, which represent the development options of the power plants, have been considered.

1. INTRODUCTION

In comparison to fossil and nuclear power sources, geothermal resources are a clean, reliable and abundant source of energy, with great potential to meet an increasing share of the world´s expanding energy needs (Rybach, 2003). Such energy is inexorably gaining momentum in many parts of the world endowed with the resource, due to burgeoning populations and escalating economies. It is presently being utilised in 78 countries worldwide for both direct and indirect uses (Lund et al., 2010).

Kenya is the first country in Sub-Sahara Africa to tap power from the Earth's crust in a significant fashion (Karekezi and Kithyoma, 2003). The country has plentiful geothermal resources that have not been exploited to full potential. The resources are located in the Kenyan Rift (Figure 1), and recent studies of geothermal explorations reveal that geothermal potential in the rift exceeds 10,000 megawatts of electricity (MWe). The Least Cost Power Development Plan (2010-2030) prepared by the Government of Kenya indicates that geothermal plants have the lowest unit cost and therefore are suitable for base load and are thus, recommended for additional expansion (Republic of Kenya, 2010). Geothermal energy in Kenya is primarily utilised for electricity production, and this currently stands at 276 MWe. Direct uses of geothermal energy in the country include greenhouses, drying agricultural products, swimming, therapeutic bathing, and aquaculture. More than 14 geothermal sites have been identified in the Kenyan Rift (Figure 1). These prospect fields from south to north are Lake Magadi, Suswa, Longonot, Olkaria, Eburru, Badlands, Menengai, Arus Bogoria, Lake Baringo, Korosi, Paka, Silali, Emuruangogolak, Namarunu and Barrier Volcano. Only the Olkaria and Eburru geothermal fields have been developed. The other fields are at various reconnaissance and surface exploration stages.

The main environmental concerns arising from geothermal operations are associated with discharge of non-condensable gases such as hydrogen sulphide (H_2S), carbon dioxide and methane into the atmosphere. Hydrogen sulphide has the greatest environmental concern not only because of its noxious smell in low concentrations but also due to its toxicity and health impacts at high concentrations, and its tendency to concentrate in hollows and low-lying areas due to its high density (Kristmannsdóttir et al., 2000). The current geothermal energy generation at Greater Olkaria geothermal field is 273.7 MW. The government of Kenya has an ambitious strategy to increase geothermal power generation by over 785 MW by 2017, out of which 700 MW will be sourced from Olkaria. In order to determine cumulative environmental impacts associated with hydrogen sulphide, various modeling techniques have been employed in distinct parts of the world. This study uses CALMET/CALPUFF computer-based dispersion model to investigate the air quality effects of four stages in the proposed development of the Olkaria geothermal field. The assessment has been confined to the potential effects of hydrogen sulphide.

2. STUDY AREA

The study focuses on the Olkaria geothermal area (Figure 2) in Kenya located on the floor of the Kenyan rift.

3. METHODS USED IN THE ASSESSMENT

The assessment has been undertaken using the CALMET/CALPUFF modeling system to predict the ground level concentrations of hydrogen sulphide expected as a result of emissions from existing and yet to be developed geothermal power stations at Olkaria. The CALMET/CALPUFF modeling system is an advanced wind-field based dispersion model designed to simulate pollutant dispersal on both small and large scale modeling domains. The CALMET model prepares the meteorological data into an hourly four-dimensional database required by CALPUFF. CALPUFF is then used to simulate the transport and diffusion of the emissions and to predict the concentrations of emissions at a user-specified grid of receptors for nominated averaging periods.

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The CALMET/CALPUFF suite of models is approved by the United States Environmental Protection Agency (US EPA) for air quality assessments. The models require meteorological data, topographical data and data on land-use to simulate the wind fields and other dispersion information generated by CALMET. This information is also needed by CALPUFF.
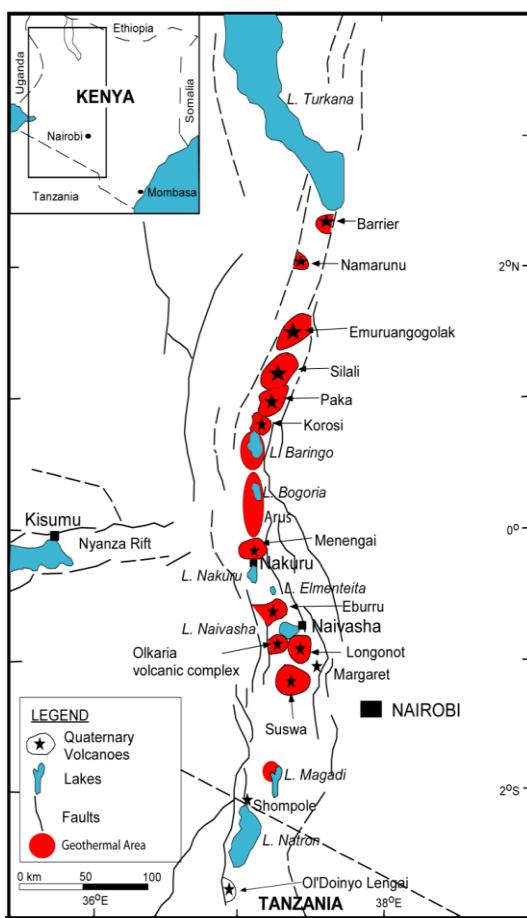

**Figure 1: Kenya geothermal fields and prospects**
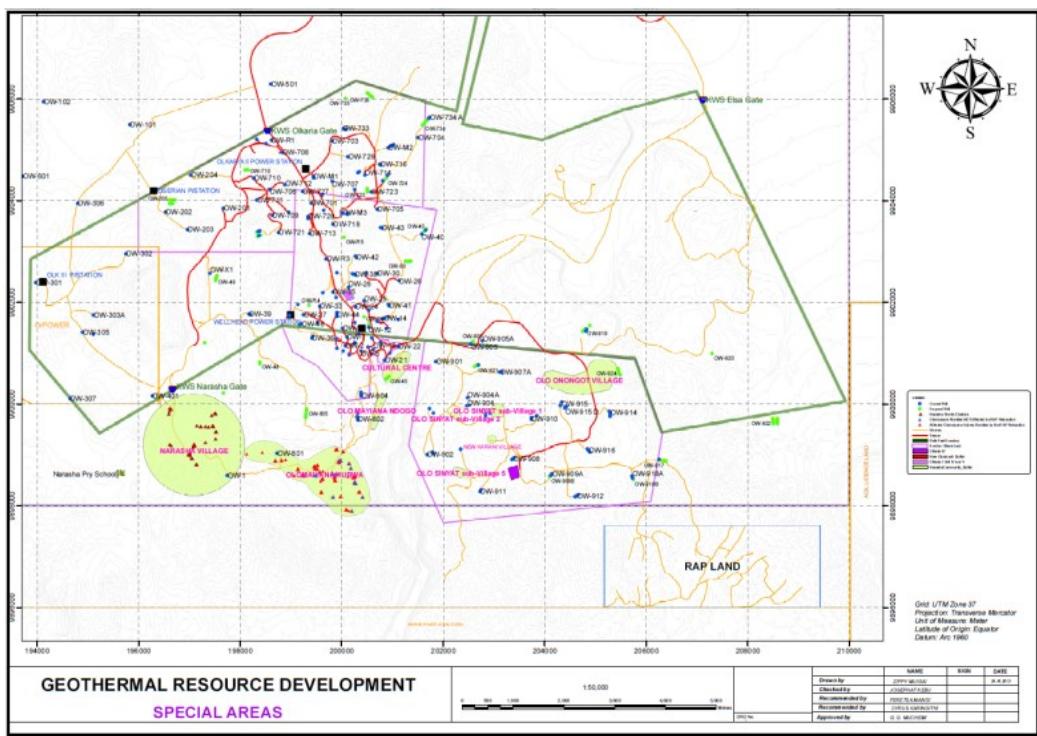
Figure 2: Olkaria geothermal development area and surrounds

4. AIR QUALITY ASSESSMENT CRITERIA

Kenya has not yet developed ambient air quality standards for hydrogen sulphide. The draft Environmental Management and Co-ordination (Air Quality) Regulations, 2008 and the Factories and Other Places of Work (Hazardous substances) Rules, 2007 refer to occupational exposure limits of (14 mg/m^3) 10 ppm as a 8 hour time-weighted average (TWA) and (21 mg/m^3) 15 ppm as a short-term exposure limit. These are occupational health standards and are not appropriate for assessing ambient air exposures to which the general public might be exposed. For ambient exposures it is necessary to consider both health and potential nuisance effects.

Hydrogen sulphide odour detection limit of 0.0046 ppm (7 μg/m^3) has been used as per the study by Nagy (1991). At this concentration, no harmful effects to human health are known. At higher concentrations, where hydrogen sulphide is extremely toxic, it produces complete fatigue of the olfactory nerve and its presence cannot be detected. Its odour therefore serves as an important warning of its presence well before the concentrations reach dangerous levels.

The WHO 24-hour health-based guideline of 0.1 ppm has been used to assess impacts beyond the immediate power station boundary and to define the area, which should not be inhabited or used for residential purposes. Standards applicable within the power station should be based on the occupational health guidelines. It is also proposed that areas supporting commercially, culturally or scientifically important vegetation should not be permitted to experience exposures above 0.03 ppm long-term average.

5. MODELING CASES AND EMISSIONS

Three development cases (Cases 1 to 3) have been modeled for Olkaria. These show the expected air pollution effects of each case for 1-hour, 24-hour and one-year averaging periods. Each case represents the cumulative effects of all power stations expected to be operating for the particular case. The emission scenarios included:

- **Case 1:** Operations include Olkaria I Units 1, 2, 3, 4, 5 and 6 plus Olkaria II, Units 1, 2 and 3 plus the 4.7 MWe well-head power plant at OW37. The total installed capacity is 364.7 MWe.
- **Case 2:** Case 2 operations include all emission sources that apply for Case 1, but this case assumes that Olkaria I has been refurbished with new Units 1, 2 and 3 rated at 15 MWe each. Further it is assumed the non-condensable gases are released in new cooling towers with similar characteristics to those used for Olkaria II. In addition Case 2 assumes that Olkaria IV, Units 1 and 2 are operating as are new well-head power plants at OW43 and OW914. The total installed capacity is 545.3 MWe.
- **Case 3:** Case 3 assumes that all Case 2 emissions are operating and that 140 MWe Olkaria V Units 1 & 2 and 140MWe Olkaria VI Units 1 and 2 are operating. The total installed capacity is 825.3 MWe.

Many of the power plants have multiple emission points and the total number of points modeled in each case and the total estimated emission rate of hydrogen sulphide is shown below:

- Case 1– 28 emission points, 120 g/s
- Case 2– 51 emission points, 193 g/s
- Case 3 – 67 emission point, 307 g/s.

6. RESULTS AND ANALYSIS

The prediction results for each of the three cases for 1-hour, 24-hour and annual average hydrogen sulphide concentrations (in ppm) are illustrated below.

6.1 Annual and seasonal wind roses

Figure 3 shows seasonal and annual wind roses derived from the modeling file produced by CALMET for a location close to the Olkaria II Power Station. Note the seasons have been taken to be southern hemisphere summer (December, January and February), autumn (March, April and May) etc. seasons. The predominant wind directions over the year are from the south and south-southeast.

6.2 Case 1

Figures 4, 5 & 6 show the predicted maximum 1-hour and 24-hour and annual average hydrogen sulphide concentrations for Case 1 operations. The operating power stations include the existing Olkaria I (Units 1, 2 and 3), the existing Olkaria II (Units 1, 2 and 3), the existing well-head power station OW37 and Olkaria I (Units 4, 5 and 6) under construction.

The maximum predicted 1-hour average hydrogen sulphide concentrations were 4.78 ppm, which was predicted to occur at 200.450 km East and 9900.612 km North (Arc 1960 coordinates). This is in the area to the northeast of Olkaria I (Units 1, 2 and 3) and Olkaria I (Units 4, 5 and 6) and is mostly likely a consequence of emissions from Olkaria I (Units 1, 2 and 3).

Error! Reference source not found. 5 shows the predicted 24-hour average hydrogen sulphide concentrations. It can be seen that the WHO 24-hour guideline of 0.1 ppm is predicted to be exceeded in the high ground to the northwest of Olkaria I and northeast of Olkaria II. There are no residential areas located within the 0.1 ppm 24-hour average contour.

Error! Reference source not found. shows the area affected by predicted annual average hydrogen sulphide concentrations above the 0.03 ppm level. It is suggested that an assessment criterion of 0.03 ppm should be used to assess annual average hydrogen sulphide concentrations.

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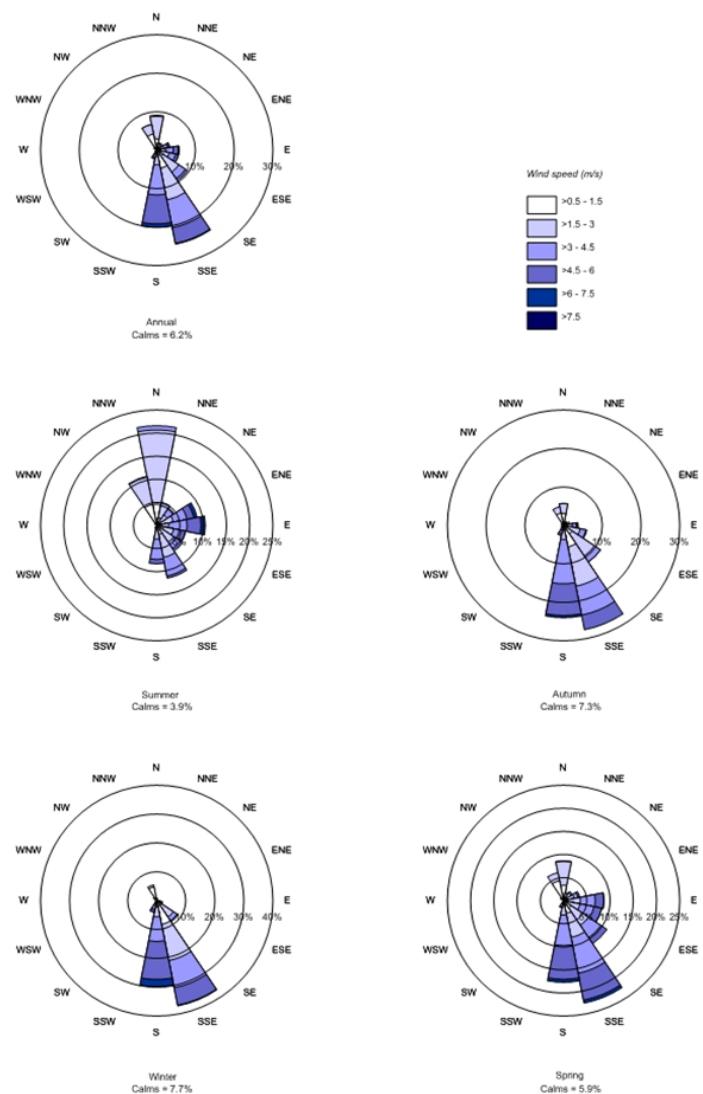
Figure 3: Olkaria wind roses derived from Calmet Model at 10m above ground level
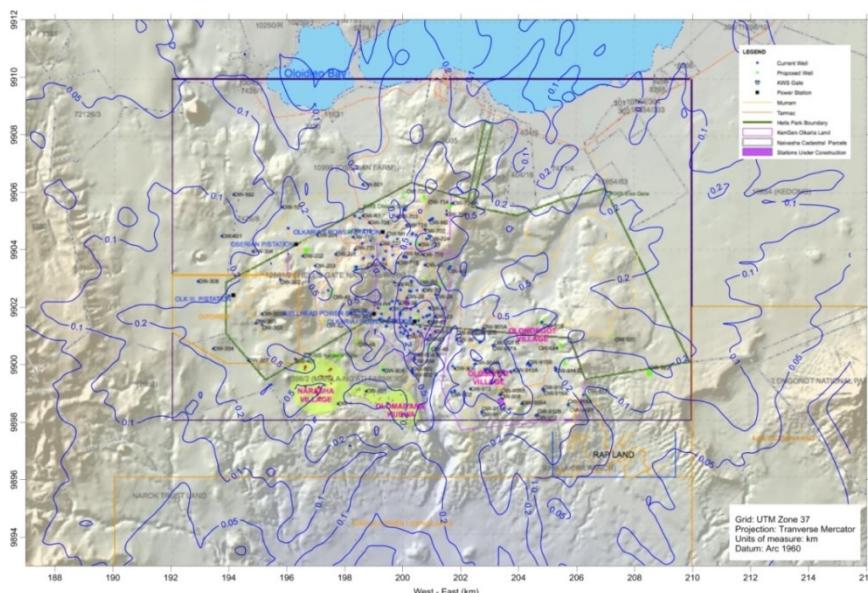
Figure 4: Predicted maximum 1-hour average hydrogen sulphide concentrations for Case 1 operations (in ppm)

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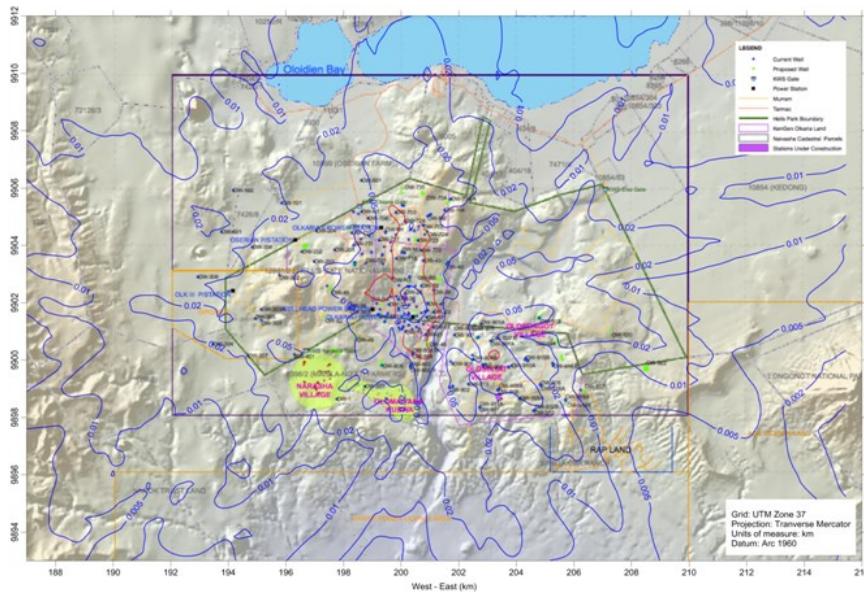
Figure 5: Predicted maximum 24-hour average hydrogen sulphide concentrations for Case 1 operations (in ppm)
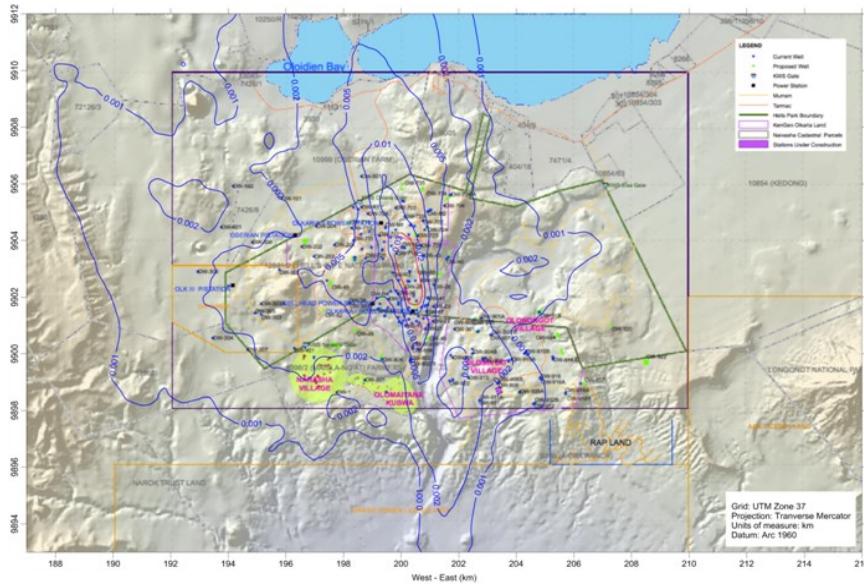
Figure 6: Predicted annual average hydrogen sulphide concentrations for Case 1 operations (in ppm)

6.3 Case 2

Figures 7, 8 & 9 show the predicted maximum 1-hour, 24-hour and annual average hydrogen sulphide concentrations for Case 2 operations. The operating power stations include the re-furbished Olkaria I (Units 1, 2 and 3), the existing Olkaria II (Units 1, 2 and 3) and the existing well-head power station at OW-37. In addition, Olkaria I (Units 4, 5 and 6), Olkaria IV (Units 1 and 2) and well-head power stations at OW-914 and OW-43, all of which are under construction have been assumed to be operating.

The maximum predicted 1-hour average hydrogen sulphide concentrations were 6.39 ppm which was predicted to occur 201.116 km East and 9903.609 km North (Arc 1960 coordinates). This is in the area close to the well-head power station at OW-43. It seems likely that this is due to the proximity of the elevated terrain that rises steeply to the north of this emission source.

Figure 8 shows the predicted 24-hour average hydrogen sulphide concentrations for Case 2. It can be seen that the WHO 24-hour guideline of 0.1 ppm is predicted to be exceeded in several disconnected areas. Most of these are associated with the high ground to the northwest of Olkaria I and northeast of Olkaria II and around OW-914. There are no residential areas located within the 0.1 ppm 24-hour average contours. It is interesting that the relative small well-head power station makes a disproportionate contribution to ground-level concentrations of hydrogen sulphide. This is a result of the less buoyant plumes from these sources compared with the larger power stations.

Figure 9 shows the annual average hydrogen sulphide concentrations. No commercial agricultural enterprises areas are predicted to experience annual average concentrations above the 0.03 ppm level.
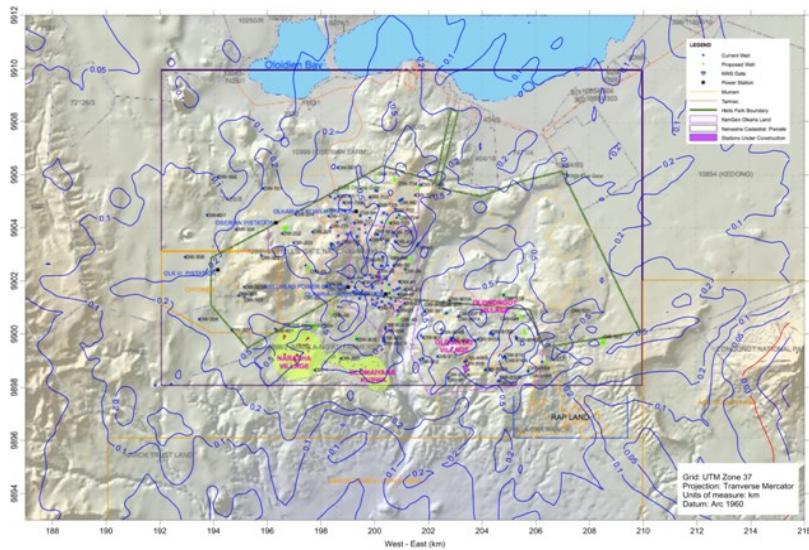
Figure 7: Predicted maximum 1-hour average hydrogen sulphide concentrations for Case 2 operations (in ppm)
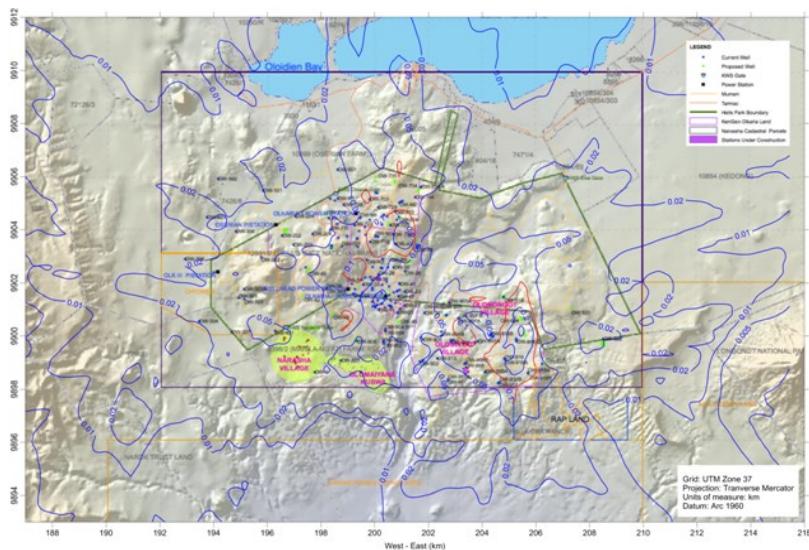
Figure 8: Predicted maximum 24-hour average hydrogen sulphide concentrations for Case 2 operations (in ppm)
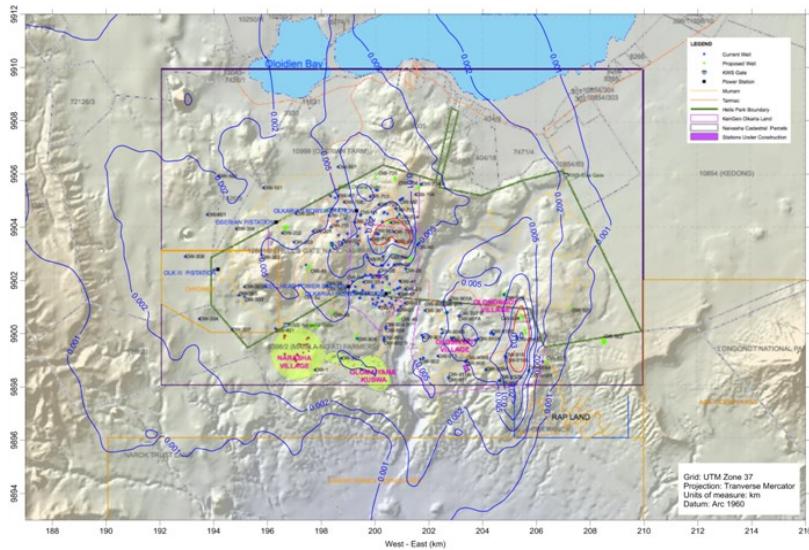
Figure 9: Predicted annual average hydrogen sulphide concentrations for Case 2 operations (in ppm)

6.4 Case 3

Figures 10, 11 & 12 show the predicted maximum 1-hour, 24-hour and annual average hydrogen sulphide concentrations for Case 3 operations. Again, the operating power stations include all the power stations included in Case 2 and 280 MWe Olkaria V &VI.

As before the maximum predicted 1-hour average hydrogen sulphide concentrations were 6.48 ppm which was predicted to occur 201.116 km East and 9903.609 km North (Arc 1960 coordinates). As for the earlier cases this is to the immediate north of the well-head power station at OW43.

Figure 11 shows the predicted 24-hour average hydrogen sulphide concentrations for Case 3. It can be seen that the WHO 24-hour guideline of 0.1 ppm is predicted to be exceeded in several disconnected areas around power stations. There are no residential areas located within the 0.1 ppm 24-hour average contours.

Figure 12 shows the predicted annual average hydrogen sulphide concentrations for Case 3. No agricultural enterprises are predicted to experience annual average concentrations above the 0.03 ppm level.
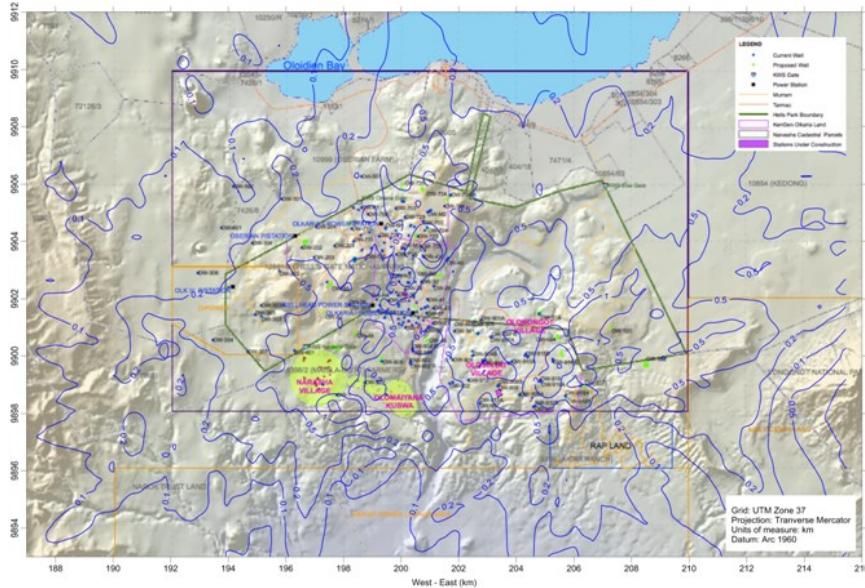

Figure 10: Predicted maximum 1-hour average hydrogen sulphide concentrations for Case 3 operations (in ppm)
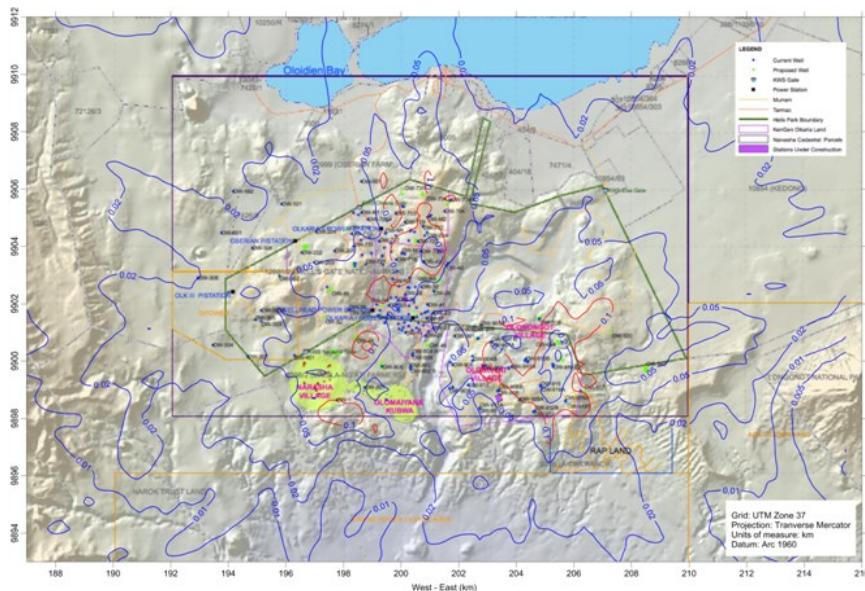

Figure 11: Predicted maximum 24-hour average hydrogen sulphide concentrations for Case 3 operations (in ppm)
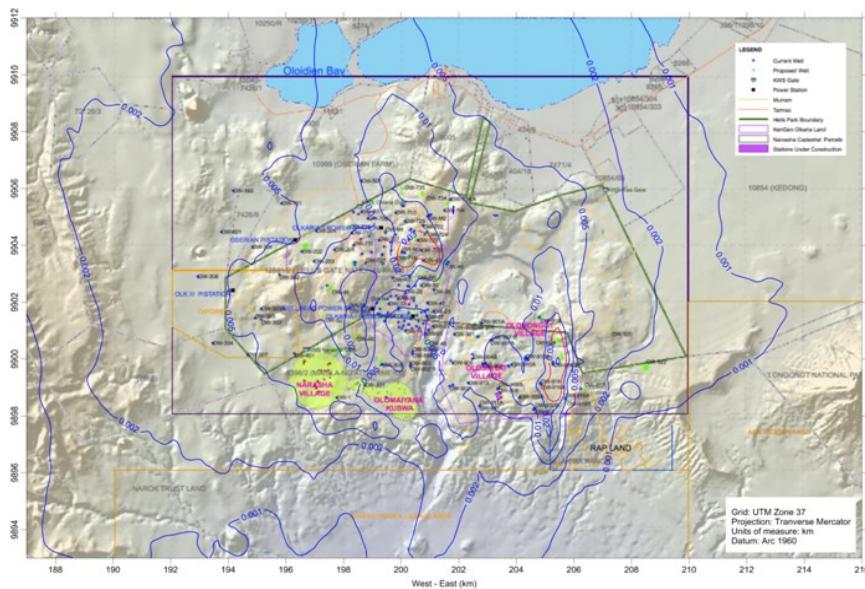
Figure 12: Predicted annual average hydrogen sulphide concentrations for Case 3 operations (in ppm)

7. CONCLUSION

The model results presented in this report show maximum 1-hour, maximum 24-hour and annual average predicted hydrogen sulphide concentrations for three stages in the development of the Olkaria geothermal field. The maximum 1-hour average concentrations can be used to gauge the areas of land where hydrogen sulphide odours will be expected to occur. Odour is detectable (0.0046 ppm) over large areas extending to 10 km and further from emission sources at Olkaria. In the light of the predicted increase in the size of areas predicted to experience odour and the increase in frequency at which odour is predicted to be above the odour detection level it will be important to establish officially approved assessment criteria for hydrogen sulphide based on odour.

No residential areas are predicted to experience 24-hour average hydrogen sulphide concentrations above the WHO 0.1 ppm level. Some areas close to emission sources (Olkaria I in Case 1 and Olkaria I and IV in Cases 2 and 3) are predicted to experience annual average hydrogen sulphide concentrations above the 0.03 ppm level. These do not include areas where commercial crops are grown but includes the area to the northwest of Olkaria I where flower growing trials where undertaken in the early 1990s. No adverse effects on flowers due to hydrogen sulphide emissions were found in these trials.

No effects are expected on the health of commercially grown crops, but some small areas close to the power stations at Olkaria are predicted to experience annual average hydrogen sulphide concentrations above the 0.03 ppm level. This may present an opportunity to undertake before and after vegetation surveys to see if any effects can be identified on local native plant species.

There is a need to verify the estimated emissions of hydrogen sulphide used in these scenarios. This should be done both for existing emissions and for new sources when new wells are developed and hydrogen sulphide emissions data can be collected.

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