AIR QUALITY ASSESSMENT:
PAPUA NEW GUINEA LIQUEFIED NATURAL GAS PROJECT (UPSTREAM)

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Prepared for
Coffey Natural Systems Pty Ltd

by

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1 INTRODUCTION

This report has been prepared by Holmes Air Sciences for Coffey Natural Systems. Its purpose is to provide an assessment of the effects of atmospheric emissions associated with the upstream component (see later) of the Papua New Guinea Liquefied Natural Gas Project (PNG LNG Project). Figure 1 shows an overview of the project.

The PNG LNG Project involves the development of a number of gas fields and facilities in a series of development phases to produce liquefied natural gas (LNG) for export. The development will also produce condensate. The development of the Hides, Angore, and Juha gas fields and blowdown of the gas caps at the existing Kutubu, Agogo and Gobe oil fields will supply the gas resources. An extensive onshore and offshore pipeline network will enable transportation of the gas to a new LNG Plant near Port Moresby and stabilised condensate to the existing oil processing and storage, and offloading facilities at the Kutubu Central Processing Facility and Kumul Marine Terminal respectively. Small amounts of condensate are also produced at the LNG Facilities site.

Esso Highlands Limited (Esso), a Papua New Guinea subsidiary of the Exxon Mobil Corporation (ExxonMobil), is the operator of the PNG LNG Project. The PNG LNG Project will be developed in five phases over a period of 10 years to ensure reliability and consistent quality of supply of LNG over the 30 year life of the project. For assessment purposes the project has been divided into two parts, (1) upstream and (2) LNG Facilities. Upstream refers to all project components from the wellhead to the inlet of the LNG Plant and associated infrastructure. The upstream components span three PNG provinces: Western, Southern Highlands and Gulf.

A list of the proposed developments associated with the upstream components is provided below, and Figure 1 shows a schematic of facilities and pipelines:

1.1 Upstream Development Components

- Hides gas field development:
  - Seven wellpads with a total of eight new wells and re-completion of two existing wells.
  - Hides gathering system including gas flowlines from new and re-completed Hides wells.
  - Hides spineline and mono-ethylene glycol (MEG) Pipeline in the same right of way (ROW).
  - Hides Gas Conditioning Plant.
  - Hides–Kutubu Condensate Pipeline in the same ROW as the LNG Project Gas Pipeline.
- Juha gas field development:
  - Three new wellpads with four new wells.
  - Juha gathering system including gas flowlines from new Juha wells.
  - Juha spinelines and MEG Pipeline in the same ROWs.
  - Juha Production Facility.
  - Juha–Hides pipelines right of way (ROW) containing three pipelines including Juha–Hides Rich Gas Pipeline, Juha–Hides Liquids Pipeline and Hides–Juha MEG Pipeline.
- Angore gas field development:
  - Two new wellpads with two new wells.
  - Angore gathering system including gas flowlines from new Angore wells.
  - Angore spineline and Angore MEG Pipeline to Hides Gas Conditioning Plant, both in the same ROW.

- Gas from existing fields:
  - Gas treatment at the Agogo Production Facility and a new Agogo Gas Pipeline from the Agogo Production Facility to LNG Project Gas Pipeline.
  - Gas treatment at the Gobe Production Facility and a new Gobe Gas Pipeline from the Gobe Production Facility to LNG Project Gas Pipeline.
  - Gas treatment at the Kutubu Central Processing Facility and a new Kutubu Gas Pipeline from the Kutubu Central Processing Facility to the LNG Project Gas Pipeline.
  - South East Hedinia gas field development: one new wellpad and two new wells; new gathering system including gas flow lines from the South East Hedinia new wells to the Kutubu Central Processing Facility in the same ROW as the Kutubu Gas Pipeline.
- Kopi scraper station.
- LNG Project Gas Pipeline:
  - Onshore: from Hides Gas Conditioning Plant to Omati River Landfall.
  - Offshore: Omati River Landfall to Caution Bay Landfall.

1.2 LNG Facilities Development Components

- Onshore LNG Plant including gas processing and liquefaction trains, storage tanks, flare system and utilities.
- Marine facilities including jetty, LNG and condensate export berths, materials offloading facility and tug moorage.

1.3 Supporting Facilities and Infrastructure

In addition to the principal gas production, processing and transport, and LNG production and export facilities, the project will involve the following permanent infrastructure and facilities:

- New roads and upgrade of existing roads.
- New bridges and upgrade of existing bridges.
- Upgrade of two existing airfields (upstream at Komo and Tari).
- New helipads (multiple).
- New wharf and an upgrade of the existing Kopi roll-on, roll-off facility.
- Water supply systems and pipelines, wastewater and waste management facilities.
- Operations Camps (at Hides, Juha and Tari).

A series of temporary works and access roads will also be required during the construction phase, including:

- Construction camps (multiple).
- Material/pipe laydown areas.

In summary, the report provides the following:

- A brief description of the project focussing on those aspects important from the perspective of air quality.
- A review of the likely existing air quality.
- A review of existing dispersion conditions.

- Information on air quality assessment criteria to be used in assessing the effects of atmospheric emissions on ambient air quality.
- Predictions of ground-level concentrations of atmospheric emissions made using a computer-based dispersion model for components of the project where emissions may be significant.

Project activities will occur over a wide geographical area and in some cases activities occur in association with existing operations. The main text of the EIS provides a more comprehensive discussion of the entire project and its relation to existing operations than is provided in this report.

2 FURTHER DESCRIPTION OF THE PROJECT

Figure 2 shows the location of the production fields, production facilities and the route of the gas pipeline to the point where it reaches the LNG Plant at Caution Bay approximately 20 km northwest of Port Moresby. This includes an overland section running from the Hides Gas Conditioning Plant to the Omati River Landfall (approximately 288 km) and an undersea portion from the Omati River Landfall to the LNG Plant; a distance of approximately 407 km.

The objective of the project is to deliver gas from wells in the Hides, Angore, Juha, Kutubu, Agogo, Moran and South East Hedinia in the highlands to the LNG Plant. This will require a new processing facility to be constructed near the Hides Gas Field, i.e. the Hides Gas Conditioning Plant and a new gas production facility at Juha, i.e. the Juha Production Facility. The location of the Hides Gas Conditioning Plant is indicated on Figure 2 and a detailed plot plan is provided on Figure 3.

Gas will be liquefied at the facility to be developed on Portion 152 (Caution Bay) and LNG product will be transported by sea to international gas markets. This latter activity will form the LNG Facilities component of the project which is assessed in a separate document. The project would develop the following:

- Hides field.
- Juha field.
- Angore field.

In addition, some gas that is currently being injected or flared at Agogo, Moran, Kutubu and Gobe will also be sent to the LNG gas pipeline.

The production facility at Juha will comprise equipment to separate oil products into gas and liquids, which will flow to the Hides Gas Conditioning Plant. This will include the following:

- Receiver and slug catcher.
- Gas processing, dehydration and compression plant.
- Retention pond.
- Utilities and control room.
- Flare.

The Hides Gas Conditioning Plant will also receive gas and liquids from the Hides and Angore fields. Liquids will flow through a pipeline to the existing Kutubu Central Processing Facility. The facilities at Hides will include the following:

- Receiver and slug catcher.
- Gas processing, dehydration and compression units.
- Condensation stabilisation equipment.
- Power generation and backup essential generator.
- Retention pond.
- Utilities and control room.
- Flare.

Each gas field will have a gas gathering system. Short gas pipelines will also be constructed to transfer gas from the Agogo, Kutubu, Gobe, South East Hedinia and Moran facilities to the PNG LNG Project gas pipeline.

3 AMBIENT AIR QUALITY ASSESSMENT CRITERIA AND EMISSION LIMITS

This section discusses the question of ambient air quality and the related question of emission limits.

The World Bank has published policies (World Bank, 1999) that are intended to guide the Environmental Assessment (EA) process for projects seeking Bank financing. The World Bank does not by itself specify ambient air quality standards or emissions limits. The policies specify that in establishing air quality goals for a project the EA process should take note of the national environmental action plans, the country's overall policy framework, and national legislation amongst other factors. The World Bank has also published a document known as the "*Pollution Prevention and Abatement Handbook*" which specifies in-stack emission concentrations that are normally acceptable to the Bank and these are discussed later.

The key method used by regulatory agencies around the world to manage air quality is to (1) specify concentration limits for pollutants in the ambient air and (2) to specify concentration limits at the point of emission (i.e. in-stack concentration limits also known as emission limits).

Environmental impacts arise through the exposure to pollutants in the ambient air and consequently the ambient air concentration limits (or assessment criteria as they will be referred to in this report) are the key to protecting human health and protecting other elements of the environment such as the health of flora and fauna. The relationship between emission concentrations and ambient air concentrations is complicated. Ambient concentrations depend not only on the in-stack concentration, but also on the volume flux of the emission (i.e. the size of the source), the plume rise, the stack height, existing levels of pollution from other sources and the dispersive capacity of the atmosphere. This means that compliance with an emission limit may or may not lead to compliance with the ambient air assessment criteria. However, in every case it is the ambient concentrations that are critical for protecting the environment. Emission limits are set to ensure that equipment is operated efficiently and that appropriate technology is used in plant, taking account of the environment in which it is operated.

Thus emission limits are primarily used to ensure that appropriate control technologies are applied for a particular environment. For example, a large urban area, such as Los Angeles or Houston, with multiple emissions sources including oil refineries, traffic, airports etc may need to employ stringent controls on nitrogen oxides (NO_x) or volatile organic compounds (VOCs) in order to manage photochemical smog or to ensure that cumulative effects of many thousands of emission sources are managed effectively. These same limits may not be required in other areas.

For remote areas of PNG where there are no other sources of combustion emissions the primary air quality management objective is to ensure that the emissions do not, by themselves, or cumulatively (with existing or proposed emission sources), give rise to ambient concentrations of emissions that could cause environmental harm. Further it is necessary to ensure that the airshed has sufficient capacity to disperse the emissions from additional sources should an expansion be required.

3.1 Ambient Assessment Criteria

As identified in the previous section, the project will need to comply with ambient air quality standards designed to protect human health, flora and fauna and other aspects of the environment.

Ambient air quality standards include the effects of emissions from the project and from all other sources including natural sources and nearby industrial and domestic sources that could give rise to cumulative effects.

As noted earlier, the World Bank does not directly set ambient air quality standards for projects it funds, but has reviewed the air pollution effects of selected pollutants and makes recommendations as to acceptable ambient standards based on information provided by other authorities, most notably the World Health Organisation (WHO). Further, it should be noted that the WHO does not specify air quality standards but rather provides guidance information to assist national governments to derive appropriate standards after taking account of climatic, social, economic and other factors.

The standards for sulphur dioxide, nitrogen oxides, VOCs and particulate matter (which are the relevant emissions for this project) are discussed below.

The World Bank (1998) guidelines rely on information contained in a publication by the WHO (1987). The WHO (1987) publication was updated in 2000 (WHO, 2000) and some of the guideline values were revised. Further revisions to the guidelines values for particulate matter, nitrogen dioxide and sulphur dioxide were made in 2005 (WHO, 2005). To cover the full range of emissions relevant to the PNG LNG Project it is necessary to refer to a number of authorities and guidelines developed at different times. The values chosen to assess the project are intended to reflected current values which would apply in developed economies and thus should provide a high level of protection.

3.1.1 Sulphur dioxide

The World Bank recommends (World Bank, 1998) that in the long-term, countries should seek to ensure that ambient exposure to sulphur dioxide does not exceed the guidelines recommended by the World Health Organisation (WHO). The 2005 guidelines for sulphur dioxide are:

1. 10-minute average 500 $\mu g/m^3$
2. 24-hour average 20 $\mu g/m^3$.

The new 24-hour guideline of 20 $\mu g/m^3$ is significantly lower than the 125 $\mu g/m^3$ value suggested previously by the WHO (2000) and the 2005 document notes that the 24-hour average guideline of

20 µg/m^3 may be difficult for some countries to meet. The document suggests the use of 24-hour average interim targets as follows:

1. Interim target 1 (24-hour average), 125 µg/m^3
2. Interim target 2 (24-hour average), 50 µg/m^3.

WHO has withdrawn the annual average guideline of 40 to 60 µg/m^3 on the basis that compliance with a 24-hour average of 20 µg/m^3 would automatically ensure compliance with the annual guideline of 40 to 60 µg/m^3.

The [1]Interim targets set by WHO (2005) are intended for use in areas where pollution is high. The targets aim to promote a shift from high air pollutant concentrations to lower air pollutant concentrations. For the upstream assessment the sulphur dioxide guidelines are not used because emissions of sulphur dioxide are too low to justify a full assessment (see later).

In cases where the Interim targets are used it is useful to refer to the old annual guideline.

For the upstream project area the sulphur content of the gas used to fuel turbines is very low[2] and there is no prospect of the sulphur dioxide assessment criteria being exceeded by emissions from the project. For this reason no modelling of sulphur dioxide emissions is undertaken in this assessment.

3.1.2 Carbon monoxide

Guidelines for carbon monoxide are provided in the WHO (1987) and WHO (2000) documents. The carbon monoxide guidelines are not revisited in the 2005 document (WHO, 2005). The guidelines recommended in 2000 are:

1. 15-minute average - 100,000 µg/m^3
2. 30-minute average – 60,000 µg/m^3
3. 1-hour average – 30,000 µg/m^3
4. 8-hour average – 10,000 µg/m^3.

It is relevant to note that carbon monoxide emissions from the turbines are very low, and as with sulphur dioxide there is no prospect that the carbon monoxide guidelines will be exceeded by emissions from the project.

3.1.3 Hydrogen sulphide

The hydrogen sulphide concentration in the gas being processed is low and as hydrogen sulphide is converted to sulphur dioxide during combustion of the gas, in practice there will be no emission of hydrogen sulphide. The World Bank (1998) sets a standard of 5 mg/m^3 (3.3 ppm) at the boundary to protect against odour impacts and this is included for completeness.

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[1] WHO provides a discussion of the purpose of Interim targets on Page 8 of the guideline document (WHO, 2005).

[2] This comment is based on measurements of gas at the Kutubu Central Processing Facility. The data shows that total sulphur concentrations are less than 0.57 mg/Nm^3. The corresponding emission rate of SO_2 will be less than 0.05 g/s for Titan 130 turbines and even less for other plant.

3.1.4 Nitrogen dioxide

The World Bank recommends (World Bank, 1998) that in the long-term countries should seek to ensure that ambient exposure to nitrogen dioxide does not exceed the guidelines recommended by WHO. Based on the 1987 recommendations the ambient goals are:

1. 1-hour average - 400 µg/m^3 (WHO, 1987)
2. 24-hour average – 150 µg/m^3 (WHO, 1987)
3. Annual average – none specified by (WHO, 1987).

In its more recent reviews (WHO, 2000) and (WHO, 2005), the WHO revised the 1987 guideline values to half the 1-hour average from 400 to 200 µg/m^3 and introduced a long-term guideline value of 40 µg/m^3. No reference is made in WHO (2000) or WHO (2005) documents to a 24-hour guideline. Thus the new values are:

1. 1-hour average - 200 µg/m^3 (WHO (2000) and WHO (2005))
2. Annual average – 40 µg/m^3 (WHO (2000) and WHO (2005)).

In the context of the current study it is useful to consider the statements made by the WHO in revising the guidelines. The following is an excerpt from WHO (2000) (Page 179):

"*Despite the large number of acute controlled exposure studies on humans, several of which used multiple concentrations, there is no evidence for a clearly defined concentration –response relationship for nitrogen dioxide exposure. For acute exposures, only very high concentrations (1990 µg/m^3; >1000 ppb) affect healthy people. Asthmatics and patients with chronic obstructive pulmonary disease are clearly more susceptible to acute changes in lung function, airway responsiveness and respiratory symptoms. Given the small changes in lung function (<5% drop in FEV1 between air and nitrogen dioxide exposure) and changes in airway responsiveness reported in several studies, 375 –565 µg/m^3 (0.20 –0.30 ppm) is a clear lowest-observed-effect level. A 50% margin of safety is proposed because of the reported statistically significant increase in response to a bronchoconstrictor (increased airway responsiveness) with exposure to 190 µg/m^3 and a meta-analysis suggesting changes in airway responsiveness below 365 µg/m^3. (The significance of the response at 190 µg/m^3 (100 ppb) has been questioned on the basis of an inappropriate statistical analysis.) On the basis of these human clinical data, a 1-hour guideline of 200 µg/m^3 is proposed. At double this recommended guideline (400 µg/m^3) there is evidence to suggest possible small effects in the pulmonary function of asthmatics. Should the asthmatic be exposed either simultaneously or sequentially to nitrogen dioxide and an aeroallergen, the risk of an exaggerated response to the allergen is increased. At 50% of the suggested guideline (100 µg/m^3, 50 ppb) there have been no studies of acute response in 1 hour.*"

The above discussion suggests that there is a reasonable margin of protection in applying the 200 µg/m^3 (1-hour average) criterion for assessing the effects of NO_2 as has been done for this project.

3.1.5 Volatile Organic Compounds (VOCs)

While the World Bank "*Pollution Prevention and Abatement Handbook*" specifies emission limits for VOCs (see previous section) it makes no comments as to acceptable ambient exposures to VOCs. Part of the reason for this is that the term VOC refers to a class of compounds, not a specific compound, and members of the class have widely varying health effects. Of particular interest, from the point of view of health, are the compounds benzene, toluene, ethylbenzene and xylene referred to as BTEX compounds.

The WHO (2000) guidelines discuss the effects of exposure to BTEX compounds in terms of risk assessment rather than by recommending a concentration and associated averaging time. Instead of adopting a risk assessment for these substances it is more convenient to assess the potential effects via a screening approach. To do this it is convenient to make use of the so-called Effects Screening Levels (ESLs) values used by the Texas Natural Resources Conservation Commission (TNRCC) Toxicology & Risk Assessment (TARA) Section Staff. ESLs are used to evaluate the potential for effects to occur as a result of exposure to concentrations of constituents in air. ESLs are based on data concerning health effects, odour nuisance potential, effects with respect to vegetation, and corrosion effects. They are not ambient air standards. If predicted or measured airborne levels of a constituent do not exceed the screening level, adverse health or welfare effects would not be expected to result. If ambient levels of constituents in the air exceed the screening levels, it does not necessarily indicate a problem, but rather, triggers a more in-depth review.

The ESLs make use of several notations including short- and long-term ESLs. “Short-term” generally indicates a 1-hour averaging period. “Long-term” indicates an annual averaging period. In the text below this time descriptor has been used.

In the absence of specific guidelines, the TNRCC ESLs (2008) have been adopted and these are:

Benzene

1. 1-hour – 170 $\mu g/m^3$
2. 1-year – 4.5 $\mu g/m^3$.

Toluene[3]

1. 1-hour – 640 $\mu g/m^3$
2. 1-year – 1,200 $\mu g/m^3$.

Ethylbenzene

1. 1-hour – 2,000 $\mu g/m^3$
2. 1-year – 200 $\mu g/m^3$

Xylenes (all except p-Xylene)

1. 1-hour – 3,700 $\mu g/m^3$
2. 1-year – 370 $\mu g/m^3$

p-Xylene

1. 1-hour – 2,080 $\mu g/m^3$
2. 1-year – 208 $\mu g/m^3$.

3.1.6 Particulate Matter

The World Bank recommends (World Bank, 1998) that in the long-term, countries should seek to ensure that ambient exposure to particulate matter, especially PM_{10} does not exceed the guidelines recommended by the WHO. The WHO guidelines for particulate matter have been subject to considerable revision in recent years. The latest guidelines are discussed by WHO (2005). The

[3] Note the 1-hour ESL is less than the annual ESL for toluene. This arises because the 1-hour average criteria are based on odour and the annual criterion on toxicity. Meeting the 1-hour goal would ensure no odour impacts and no heath impacts.

guidelines now refer to concentrations of PM_{10} and $PM_{2.5}$ averaged over one year and 24-hours. As with sulphur dioxide interim targets are included. A guideline value for TSP is no longer published, but since TSP concentrations can be used to assess nuisance effects, it is useful to refer to the old 1987 guideline values and these are listed below with the guidelines for PM_{10} and $PM_{2.5}$.

PM_{10} (WHO, 2005)

1. Interim target 1, 24-hour average – 150 µg/m^3
2. Interim target 2, 24-hour average – 100 µg/m^3
3. Interim target 3, 24-hour average – 75 µg/m^3
4. Guideline, 24-hour average – 50 µg/m^3
5. Interim target 1, annual average – 70 µg/m^3
6. Interim target 2, annual average – 50 µg/m^3
7. Interim target 3, annual average – 30 µg/m^3
8. Guideline, annual average – 20 µg/m^3

$PM_{2.5}$ (WHO, 2005)

1. Interim target 1, 24-hour average – 75 µg/m^3
2. Interim target 2, 24-hour average – 50 µg/m^3
3. Interim target 3, 24-hour average – 37.5 µg/m^3
4. Guideline, 24-hour average – 25 µg/m^3
5. Interim target 1, annual average – 35 µg/m^3
6. Interim target 2, annual average – 25 µg/m^3
7. Interim target 3, annual average – 15 µg/m^3
8. Guideline, annual average – 10 µg/m^3

The WHO guideline document (WHO, 2005) discusses significance of these targets and guidelines[4]. It is clear from the discussion that the WHO considers (along with most other workers in the field) that the most harmful effects caused by particulate matter are caused by the fine fraction ($PM_{2.5}$) and that the widespread reference to PM_{10} concentrations arises because this is the measure of air quality for which, for historical reasons, the largest body of monitoring data exists.

While there is still some debate in the scientific community as to the precise mechanisms by which adverse health effects of particulate matter are mediated, it is reasonable to state that the finer fraction are more harmful because they can penetrate deeper into the respiratory system, they have a larger surface area for a given mass of particles and because particles derived from combustion processes are disproportionately represented in the finer fraction. Particles produced by combustion process will not only be finer than those produced by mechanical disturbance of dusty soils and other crustal materials, but they will also contain irritating acidic and carcinogenic substances. Most of the particulate matter liberated by the PNG LNG Project will arise during construction and will be derived from the disturbance of soils and rock. It will therefore be composed of relatively benign and coarser particles.

The WHO state that their particulate matter guidelines are based on studies that use $PM_{2.5}$ as an indicator and that the PM_{10} guidelines have been derived from by assuming that the ratio of $PM_{2.5}$:PM_{10} concentrations is 50:100. This ratio has been selected because 0.5 it is the typical ratio that applies in the urban areas in developing countries. For the PNG LNG Project none of the development sites occur in urban areas and most of the emissions of particulate matter will be from earthmoving operations. For this reason the assessment makes use of the Interim target 1 values.

[4] See Pages 9 and 10 of the guideline document (WHO, 2005).

Total Suspended Particulate Matter (TSP)

1. 24-hour average – 150 to 230 µg/m^3 (WHO, 1987 – not to be exceeded on more than 1-day per year).
2. Annual average – 60 to 90 µg/m^3 (WHO, 1987).

3.2 Summary

Table 1 summarises the assessment criteria adopted for this project. These have been developed following a review of the methodology suggested by the World Bank (World Bank, 1998) for setting such standards.

Table 1. Ambient Air Quality Assessment Criteria (units are µg/m³ unless noted otherwise)

Substance	World Bank/WHO/TNRCC	PNG	Project criterion
Sulphur dioxide - 10-minute - 24-hour Interim target 1 - 24-hour Interim target 2 - 24-hour	 500[a] (0.123 ppm) 125[a] (0.044 ppm) 50[a] (0.018 ppm) 20[a] (0.007 ppm)	(not yet developed)	 500 20
Nitrogen dioxide - 1-hour -1-year	 200[a] (0.106 ppm) 40[a] (0.023 ppm)	(not yet developed)	 200 40
Carbon monoxide - 15-minutes - 30-minutes - 1-hour average - 8-hour average	 100,000[d] (90 ppm) 60,000[d] (50 ppm) 30,000[d] (25 ppm) 10,000[d] (10 ppm)	(not yet developed)	 100,000 60,000 30,000 10,000
Hydrogen sulphide	No offensive odour < 5,000 (3.3 ppm) at boundary[b]	(not yet developed)	5,000
VOCs (BTEX) Benzene - 1-hour - 1-year Toluene - 1-hour - 1-year Ethylbenzene - 1-hour - 1-year Xylene (o or m) - 1-hour - 1-year p-Xylene - 1-hour - 1-year	 170[c] (0.022 ppm) 4.5[c] (0.862 ppb) 640[c] (0.500 ppm) 1,200[c] (0.050 ppm) 2,000[c] (0.423 ppm) 200[c] (0.0423 ppm) 3,700[c] (0.901 ppm) 370 (0.091 ppm) 2,080[c] (0.506 ppm) 208 (0.051 ppm)	(not yet developed)	 170 4.5 640 1,200 2,000 200 3,700 370 2,080 208
Particulate Matter PM_{10} - 24-hour Interim target 1 - 24-hour Interim target 2 - 24-hour Interim target 3 - 24-hour - 1-year Interim target 1 - 1-year Interim target 2	 150[a] 100[a] 75[a] 50[a] 70[a] 50[a]	(not yet developed)	 150 70

Substance	World Bank/WHO/TNRCC	PNG	Project criterion
- 1-year Interim target 3	30[a]		
- 1-year	20[a]		
$PM_{2.5}$			
- 24-hour Interim target 1	75[a]		75
- 24-hour Interim target 2	50[a]		
- 24-hour Interim target 3	37.5[a]		
- 24-hour	25[a]		
- 1-year Interim target 1	35[a]		35
- 1-year Interim target 2	25[a]		
- 1-year Interim target 3	15[a]		
- 1-year PM	10[a]		
TSP			
- 24-hour	150-230[d]		150-230
- 1-year	60-90[d]		60-90

[a] WHO (2005)
[b] World Bank (1998)
[c] TNRCC (2008)
[d] WHO (1987)

3.3 Emission limits

In establishing emission levels for a project, the World Bank requires that the levels should be established taking account of (1) the relevant legislation in the country and (2) the World Bank's "*Pollution Prevention and Abatement Handbook*". Based on the discussion presented in Section 3.1 the assessment conducted here makes use of the emissions data specified in the manufacturer's specifications for specific items of equipment. As will be seen later these limits lead to compliance with ambient concentration levels that protect the environment.

Should more stringent emission limits (i.e. lower emission limits) be applied by the PNG Department of Environment and Conservation (DEC) at the approval stage of the project then the ambient concentration would be lower and the assessment presented in this report will be conservative.

4 EXISTING AIR QUALITY

There are no ambient air quality monitoring data to establish existing levels of air pollutants. The project areas are remote from existing industrial pollution sources except those that are part of the existing facilities or those very closely related to these, for example the existing power station at the Hides Gas Plant that supplies power to the Porgera Project. The approach used in the current assessment uses a computer-based dispersion model to estimate the ground-level concentrations of emissions including those from the existing sources as well as the new sources. These are collectively assumed to be released into a pristine environment where the existing concentrations of gaseous pollutants are taken to be negligible.

5 REVIEW OF DISPERSION CONDITIONS

The dispersion model used for assessing impacts, CALPUFF (Scire et al., 2000A and 2000B), requires information about the dispersion characteristics of the area being modelled. In particular, data are required on wind speed, wind direction, atmospheric stability class[5] and mixing height[6].

There are no on-site monitoring data in any of the development areas and data for the project assessment has been generated using the Commonwealth Scientific and Industrial Research Organisation's (CSIRO) prognostic wind field and dispersion model known as TAPM (CSIRO, 2005). TAPM generates information on three-dimensional winds and vertical temperature profiles (and other parameters) over a user specified grid. The model makes use of the Australian Bureau of Meteorology's Limited Area Prediction System (LAPS) to generate the three dimensional wind fields. The computed wind fields are based on global observation of temperature, pressure, relative humidity, sea-surface temperatures etc and these parameters are adjusted to take account of local topography, land use etc so that the effects of these relatively small scale features (down to a spatial scale of approximately 1 km) on the synoptic scale winds can be taken into account. These matters are discussed in greater detail by Puri (1997). A model run for 2006 has been made for the centre of the Hides Gas Conditioning Plant at (Latitude 6.000 degrees South and Longitude 142.817 degrees East).

Figure 4 presents annual and seasonal[7] windroses prepared from the TAPM simulations for this location.

6 PROJECT EMISSIONS AND ASSESSMENT OF IMPACTS (FOR MINOR SOURCES)

This section identifies emission sources and provides quantitative estimates of emissions for significant sources. Minor emission sources are also identified and assessed in this section. The impacts of the more significant sources are assessed using dispersion modelling, which has been used to predict the ambient concentrations of emissions. The predicted concentrations have then been compared with the relevant assessment criteria (see Section 8).

Impacts due to construction of the pipeline, well pad development, drilling etc were assessed in an earlier study (Holmes Air Sciences, 2005). The details of the assessment are not repeated in this report however the conclusions reached are discussed in Sections 6.1.1 and 6.1.2.

The long-term operational phases of the project have been assessed via dispersion modelling and a comparison of the predicted concentrations of the emissions with the assessment criteria discussed

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[5] In dispersion modelling stability class is used to categorise the rate at which a plume will disperse. In the Pasquill-Gifford stability class assignment scheme, as used in this study, there are six stability classes A through to F. Class A relates to unstable conditions such as might be found on a sunny day with light winds. In such conditions plumes will spread rapidly. Class F relates to stable conditions, such as occur when the sky is clear, the winds are light and an inversion is present. Plume spreading is slow in these circumstances. The intermediate classes B, C, D and E relate to intermediate dispersion conditions.

[6] The term mixing height refers to the height of the turbulent layer of air near the earth's surface into which ground-level emissions will be rapidly mixed. A plume emitted above the mixed-layer will remain isolated from the ground until such time as the mixed-layer reaches the height of the plume. The height of the mixed-layer is controlled mainly by convection (resulting from solar heating of the ground) and by mechanically generated turbulence as the wind blows over the rough ground.

[7] The seasons selected have been referred to as summer (December to February), autumn (March to May), winter (June to August) and spring (September to November). These periods show the changes in wind patterns over the year and are not intended to describe the seasons in the tropical environment.

in Section 3 and this section merely provides quantitative estimates of the emissions for use in the modelling.

6.1 Construction

6.1.1 Pipeline

Emissions from the pipeline construction will comprise dust (TSP and PM_{10}) from vegetation clearing and the earthworks associated with road construction and trenching and emissions of NO_x, CO, SO_2 and VOCs from internal combustion engines (mostly diesel-powered earthmoving equipment). In addition, there will be minor emissions of welding fume.

The construction area will move rapidly and on average will have progressed over one hundred metres per day – approximately 10 km every two weeks. Modelling studies undertaken for open cut mine approvals in Australia show that the air quality standards for NO_2, CO, SO_2 and VOCs are not exceeded due to emissions from even large mining operations. Similarly they would not be exceeded during the pipeline construction.

For mining or construction projects where equipment usage is well defined and the works are confined to a particular area and extend over years in a regular and predictable way it is possible to analyse the operations and to use emission factor equations published by the US EPA in a document referred to as AP42 (US EPA, 1995) to develop estimates of the quantity of dust that will be generated on a long-term average basis. For the pipeline construction the meteorological conditions and ground conditions will vary depending on what part of the route is considered. For this reason it is not practicable to apply the approach that could be applied to a mine or large construction project working in fixed area for an extended period.

To provide planners and approval agencies with an indication of the potential impacts during construction, an emissions inventory has been prepared using a single value emission factor published in AP42 by the US EPA (1995) (see Chapter 13.2.3.2 of AP42). The emission factor (E) for TSP emissions from construction activity operations is E = 2.69 t/hectare/month of activity.

The factor is applicable for construction scattered over an area. The value is most applicable to construction operations with (1) medium activity level, (2) soils with moderate silt contents, and (3) in areas with a semi-arid climate. Because of this, the estimated emissions are likely to overestimate the emissions for works in PNG because the conditions are likely to be damp and significantly so if the work is undertaken during the wet season. The US EPA also notes that because the emission factor is referenced to TSP, its use to estimate particulate matter PM_{10} emissions will result in conservatively high estimates. (This is because PM_{10} particles are a sub-component of TSP particles).

The area of active construction covers an area extending along the route for a nominal distance of approximately 2.5 km and the work area will be approximately 30 m wide. The total exposed area in which active construction is taking place will therefore be approximately 7.5 ha so the estimated emission rate of TSP during construction is 20.2 t/month [7.5 ha x 2.69 t/ha], or 7.8 g/s [20.2 t/month x 10^6 g/t / (30 days/month x 24 h/day x 3600 s/h)].

TSP and PM_{10} concentrations could reach high concentrations in the immediate vicinity of earthmoving equipment during dry weather. The PNG Gas Project undertook an assessment of the air quality effects of construction works associated with the laying of the pipeline and showed the maximum predicted 24-hour average PM_{10} concentrations likely to arise due to emissions from pipeline construction. The assessment showed the area that might be affected by dust from construction along any part of the route under dry weather conditions and under the most unfavourable dispersion conditions that occur in the year. The annual average concentration was not presented as this would have little meaning for an emission source that moves over 250 m per day.

Good practice particulate matter control measures will be applied to ensure emissions are controlled to the maximum extent practicable when the construction work passes close to settled areas. Impacts will be minimised using standard mitigating measures as described in Section 6.1.5. The assessment criterion for 24-hour PM_{10} concentrations is 150 $\mu g/m^3$ (the Interim target-1 concentration referred to by WHO (2005)). This includes background PM_{10} concentrations which will vary from place to place and with seasonal conditions, but would be well under 50 $\mu g/m^3$ for most areas and under most of the conditions that would be encountered during the construction of the pipeline. Impacts were shown to be confined to within a few hundred metres of the route.

6.1.2 Construction of well pads and drilling

A number of new wells will need to be drilled and these will require the development of drill pads to support the drilling rig and act as a lay down area for equipment. Pads will vary in size but a typical pad will be approximately 1.6 ha.

Well pads will require four major pieces of construction equipment during development. These will include an excavator, a dozer(s) (Caterpillar D6 to D8), a grader and a roller / vibrator. In addition support trucks would be required to bring in supplies and haul out excavated limestone. There may also be a need for some blasting if the limestone is too hard, but current information suggests that blasting at the well pads will not be required.

The construction period for both the road and well pads from Hides 4 to Hides G pad will be approximately 34 weeks, with approximately ten weeks of this time dedicated to well pad construction. It is estimated that these works (well pads and roads) will require the excavation of slightly less than 100,000 m^3. The work is estimated to take approximately two weeks per well-site.

The works are such that it is unlikely that air quality effects from dust would be significant beyond a few hundred metres from the work area.

Drilling of the new wells is estimated to take from 90 to 130 days per well. The drilling operation will not create significant dust emissions although there will be emissions of exhaust from diesel-powered equipment.

Typically this equipment will comprise diesel generators, which will be used to power the drilling rig and various other pieces of equipment used in drilling the wells. These generators will consume approximately 8,000 to 12,000 litres of diesel per day depending on the ongoing operations.

Emissions can be calculated using the emission factors (for large (greater than 450 kW) diesel-fuelled station engines) published for use in preparation of the Australian Government's National Pollutant Inventory (NPI, 2008). The calculations are summarised in **Table 2**.

Table 2. Estimated emissions from drilling equipment

Emission	Emission factor kg/m^3 of fuel	Fuel usage (litres/day)	Emission (g/s)
Nitrogen oxides	53	12,000	7.361
Carbon monoxide	14	12,000	1.944
VOCs	1.3	12,000	0.181
PM_{10}	1.6	12,000	0.222
$PM_{2.5}$	1.6	12,000	0.222

The precise type of equipment is not known, but it can be assumed that a typical drilling set up will have a 7 m exhaust system, 0.3 m internal diameter exhaust and release exhaust gases at a temperature of approximately 450 ^{o}C with an exit velocity of approximately 20 m/s. These figures, and the emission rates in **Table 2**, have been used to undertake a screening assessment. The results of this are provided in Section 8.2.2.

6.1.3 Hides Gas Conditioning Plant

Emissions from constructing the Hides Gas Conditioning Plant will include dust from earthworks and emissions of NO_x, CO, minor quantities of SO_2 and VOCs from internal combustion engines (mostly diesel-powered earthmoving equipment).

Site preparation works are expected to take place over a 12 month period. The area enclosed by the perimeter security fence, including the area for the flare, is estimated to occupy approximately 75 ha. Approximately half of this area will need to be disturbed during construction i.e. approximately 37 ha. Major earthworks will be undertaken using earthmoving equipment likely to comprise dozers, excavators, hydraulic breakers, dump trucks, graders, mobile crusher, compactors and miscellaneous support equipment such as a fuel truck and vehicles for personnel transport. The equipment would be expected to be active approximately 65 hours per week. Excavated material will be deposited close to the site and quarried material will be recovered from nearby local quarries.

Emissions have been estimated in the same way as they were for the pipeline construction work using the single value emission factor published in AP42 by the US EPA (1995) (see Chapter 13.2.3.2 of AP42). The emission factor (E) for TSP emissions from construction activity operations is E = 2.69 t/hectare/month of activity.

The factor is applicable for construction scattered over an area. The value is most applicable to construction operations with (1) medium activity level, (2) soils with moderate silt contents, and (3) in areas with a semi-arid climate. Because the factor applies to a semi-arid area, the estimated emissions are likely to be overestimated for works in PNG where the conditions are likely to be damp and significantly so if the work is undertaken during the wet season. The US EPA note that the emission factor is referenced to TSP and the assessment criteria for dust refer to assessment criteria for TSP, PM_{10} and $PM_{2.5}$. PM_{10} particles are a sub-component of TSP particles and $PM_{2.5}$ particles are a sub-component of TSP and PM_{10}. To model the effect of these emissions it is necessary to sub-divide the TSP emission into constituent sub components that can modelled separately to take account of the differential deposition rates that are experienced by particles of different sizes. For this study the particles have been considered in three particle-size categories (0 to 2.5 μm - referred to as $PM_{2.5}$ or FP (fine particles), 2.5 to 10 μm - referred to as CM (coarse matter) and 10 to 30 μm - referred to as the Rest).

The distribution of particles in these size categories has been derived from measurements published by the SPCC (1986). The distribution of particles in each particle size range is as follows:

- $PM_{2.5}$ (FP) is 4.7% of the TSP;
- $PM_{2.5-10}$ (CM) is 34.4% of TSP; and
- PM_{10-30} (Rest) is 60.9% of TSP.

The results of the modelling are discussed in Section 8.2.3.

6.1.4 Juha Production Facility

The precise location and layout of the Juha Production Facility had not been finalised at the time of writing. However the facility will support less equipment and will require a smaller area of land than is the case for the Hides Gas Conditioning Plant. The primary emission during construction will be dust (TSP, PM_{10} and $PM_{2.5}$) generated by earthmoving equipment and via wind erosion from exposed areas under dry windy conditions.

Without detailed information on the location and areas involved it is not possible to model the dispersion of dust, however it is clear that the extent of the area in which the air quality assessment criteria will potentially be exceeded will be less than will be the case for the Hides Gas Conditioning Plant and this is the way that the construction impacts are assessed in Section 8.3.4.

6.1.5 Mitigating measures during construction

Even in remote areas where no impacts on dwellings are likely to occur, modern environmental management practice requires emissions to be controlled to minimise impacts on air quality, to protect the natural environment and to create a safe working environment. The following warrant consideration by the project to ensure that these goals are met.

- Diesel-powered equipment to be regularly serviced and diesel fuel quality standards with respect to sulphur levels will comply with local regulations.
- Speed limits will be controlled via posted speed limit signs on project unsealed roads and pipeline ROWs (when required) and vehicles kept to marked trafficable areas which will be maintained in a damp and compacted condition (when required) to enhance safety and minimise dust emissions.
- Fixed and mobile equipment (i.e., generators required for welding) will be located sensitively with respect to local people.

6.2 Operations

6.2.1 Porgera Power Station at Hides

The Porgera Power Station is part of an existing plant operated by a third party not involved in the PNG LNG Project. The reason for including the plant in the assessment is because there is no ambient air quality monitoring data that can be used to establish existing ambient concentrations of emissions in the area and therefore there is no other practical way to assess the potential cumulative effects of the emissions.

The power station comprises:

- 3 Mars 90 turbines.
- 3 Mars 100 turbines.

These units burn gas primarily but may also run on kerosene and naphtha as standby.

Emission information for the existing Porgera Power Station is provided in Table 2.

Table 3. Emission information for existing Porgera Power Station at Hides

Source	Easting (m)	Northing (m)	Elevation of base of stack (m)	Stack height (m)	Internal diam. at tip (m)	Emission Temperature (^{0}K)	Exit velocity (m/s)	Emission rate of NO_x (as NO_2 (g/s))	Emission rate of SO_2 (g/s)	Emission rate of CO (g/s)	Emission rate of PM_{10} (g/s)
Mars 90 generator set	695950[8]	9345950	1275	20	2.0	738	26.9	22.5	Neg.	1.95	Neg.
Mars 90 generator set	695950	9345950	1275	20	2.0	738	26.9	22.5	Neg.	1.95	Neg.
Mars 90 generator set	695950	9345950	1275	20	2.0	738	26.9	22.5	Neg.	1.95	Neg.
Mars 100 generator set	695950	9345950	1275	20	2.0	758	28.6	23.3	Neg.	2.02	Neg.
Mars 100 generator set	695950	9345950	1275	20	2.0	788	28.6	23.3	Neg.	2.02	Neg.
Mars 100 generator set	695950	9345950	1275	20	2.0	788	28.6	23.3	Neg.	2.02	Neg.

6.2.2 Existing Hides Gas Plant

The existing Hides Gas Plant draws power from the adjacent Porgera Power Station discussed in Section 6.2.1. The only potential emissions sources are a standby generator and waste incinerator, used as required. Thus the emissions from this existing plant can be taken to be negligible compared to the Porgera Power Station.

6.2.3 Proposed Hides Gas Conditioning Plant

The Hides Gas Conditioning Plant will be developed on a site approximately 10 km to the south of the existing Hides Gas Plant and adjacent Porgera Power Station. The plant will be augmented with additional booster compressors after Year 6 and for this assessment two development stages will be referred to. Stage 1 will apply to Years 1 to 6 and Stage 2 refers to all operations thereafter.

Figure 2 shows the layout of the proposed Hides Gas Conditioning Plant. The two stages are described below however equipment utilisation and loading will vary throughout the project life as noted below.

Emission sources for Stage 1

1. One high pressure flare/low pressure flare used during start up, process upsets and during blowdown/depressurising. The low pressure flare is also required for the MEG flash drum flash gas. Flare pilots are continuously lit.

[8] For modelling purposes all exhaust stacks have been assumed to be co-located. This will overestimate the predicted ground-level concentrations.

2. Three 21 MW RR RB211 gas-turbine gas compressors using dry low emissions technology to maintain NO_x and CO concentrations at less than 25 ppm. For Years 1 to 12 three units will operate at 100%, Years 13 to 26 three units will operate at 85% and for Years 27 to 30 two units will operate at 100%.
3. Four Tarus 60 3.4 MW Turbo Generators using dry low emission technology to maintain NO_x and CO concentrations at less than 25 ppm. These would be installed for Years 1 to 30, but only three of the four units would operate at any time.
4. One incinerator in the industrial area burning 600 Sm^3/h of fuel gas.
5. One MEG vent gas incinerator burning 475 Sm^3/h. Typically one MEG unit is operated continuously, but for approximately one day per quarter during pigging ramp up, two MEG units will be operating. It is expected that this unit could be out of service due to failure for one day every two years. This model is assessed in Section 8.3.5.
6. One Lean MEG tank equipped with fuel gas blanket. This unit will result in intermittent emissions of hydrocarbon vapours (1 Sm^3/h) of most C1 and C2 hydrocarbons during periods of increasing daily temperature.
7. One Rich MEG tank equipped with fuel gas blanket. This unit will result in continuous emissions of hydrocarbon vapours (1 Sm^3/h) of most C1 and C2 hydrocarbons.
8. One 1.2 MW essential diesel generator. Typically this would be operated one hour per quarter to one day per year if power from main turbine generators is unavailable.
9. One 3.5 MW hot oil fired heater burning 406 Sm^3/h fuel gas. This is required to provide oil heating prior to the waste heat recovery unit becoming available. It is estimated that this will operate for 12 hours over a five year period.
10. One 708 kW diesel fire water pump used in case of fire and only when the electric pump fails. Use will be infrequent and is estimated to be one hour per quarter for maintenance and one day in 30 years.
11. Diesel storage tank. This will involve minor emissions of volatile hydrocarbons.
12. Pig receivers and launchers for Hides Spineline, Angore Spineline, the Gas Pipe Line and Condensate Pipeline.

The pig launchers and receivers will release minor quantities of hydrocarbons when used, as would drains and sumps and a diesel storage tank that will also be associated with minor emissions of hydrocarbons. These minor emissions are not significant enough to include in a modelling assessment.

There will be an emergency relief valve to be located at the inlet to the Hides Gas Conditioning Plant to relieve overpressure in the spineline should the plant be unable to accept gas and the wells have failed to shutdown. The outlet of the relief valve will be connected to the HP flare. Activation of this relief valve will be an extremely unlikely event. Additionally, each well pad has an overpressure relief valve to protect the local gathering line at the wellhead from overpressure if there is a downstream restriction and the well has failed to shutdown. The relief valve outlet will be directed to a cold vent for discharge. The likelihood that this will occur is extremely low. There will also be a similar liquid relief valve to protect the MEG injection line in case of a restriction.

Items (1) to (5) in the list above have been assessed using the CALPUFF dispersion model (see Section 7). Items (6) to (12) are too small in terms of emissions and in some cases too intermittent to justify inclusion in the model.

Emission sources for Stage 2 (from Years 6 to 30)

- All equipment identified for Stage 1.
- Two 21 MW RR RB211 gas-turbine gas booster compressors using dry low NO_x emissions technology to maintain NO_x and CO concentrations at less than 25 ppm will be installed and

operated as follows: for Years 6 to 12 two units will operate at 100%, Years 13 to 26 two units will operate at 85% and for Years 22 to 30 two units will operate at 100%.

Since Stage 2 emissions involve more equipment and higher emission rates this has been used as the basis for the assessment. **Table 4** summarises the emissions from these sources and provides the associated information required for modelling.

Table 4. Emissions from Hides Gas Conditioning Plant as used in the modelling assessment

Source ID	Source code used in model	Easting (m)	Northing (m)	Stack height (m)	Height of base of stack (m)	Stack internal diameter at tip (m)	Exit velocity from stack (m/s)	Temperature (^{0}K)	NO_x emission rate as NO_2 (g/s)
1	P1COMP	700822	9336321	13.0	1705.0	2.0	32.8	768.0	1.748
2	P2COMP	700843	9336321	13.0	1705.0	2.0	32.8	768.0	1.748
3	P3COMP	700863	9336312	13.0	1705.0	2.0	32.8	768.0	1.748
[1]4	P4COMP	700780	9336348	13.0	1705.0	2.0	32.8	768.0	1.748
[1]5	P5COMP	700801	9336336	13.0	1705.0	2.0	32.8	768.0	1.748
6	P6MEGI	700948	9336253	10.0	1705.0	1.0	1.0	768.0	0.001
7	P7HPLP	701154	9336126	30.0	1705.0	1.0	18.5	789.0	2.98
8	P8EDG	700691	9336150	9.0	1705.0	0.25	55.3	768.0	2.98
9	P9HOTO	700101	9336041	12.0	1705.0	1.0	15.0	785.0	0.001
[2]10	P10POR	695950	9345950	20.0	1275.0	2.0	26.9	67.5	67.5
[2]11	P11POR	695950	9345950	20.0	1275.0	2.0	28.6	69.9	69.9

[1] Required for Stage 2 after Year 6.
[2] Porgera Power Station.

6.2.4 Proposed Juha Production Facility

As noted in Section 6.1.4 the level of detail concerning the equipment and its location within the Juha Production Facility has not been finalised. However the main items of equipment that have the potential to give rise to atmospheric emissions are known and will comprise the following:

1. One 22.3 MW RR RB211 gas-turbine gas compressor using dry low NO_x emissions technology to maintain NO_x and CO concentrations at less than 25 ppm.
2. Two Tarus 60 3.4 MW Turbo Generators using dry low NO_x emission technology to maintain NO_x and CO concentrations at less than 25 ppm.
3. One Lean MEG tank equipped with fuel gas blanket. This unit will result in intermittent emissions of hydrocarbon vapours (1 Sm^3/h) of most C1 and C2 hydrocarbons during periods of increasing daily temperature.
4. One Rich MEG tank equipped with fuel gas blanket. This unit will result in continuous emissions of hydrocarbon vapours (1 Sm^3/h) of most C1 and C2 hydrocarbons.
5. One high pressure flare/low pressure flare used during start up, process upsets and during blowdown/depressurising. The low pressure flare is also required for the MEG flash drum flash gas. Flare pilots are continuously lit.
6. One 0.6 MW essential diesel generator.
7. Two 3 kW utility water pumps.
8. Diesel storage tank. This will involve minor emissions of volatile hydrocarbons.
9. Pig receivers and launchers for Juha Spineline.

Items 1 to 3 will be significant sources of NO_x and the effects of these emissions have been assessed using a screening procedure based on the Ausplume dispersion model (see Section 7).

Table 5 outlines the emissions from the Juha Production Facility.

Table 5. Emissions from Juha Production Facility as used in the screening model assessment

Source ID	Source code used in model	[1]Easting (m)	[1]Northing (m)	Stack height (m)	[1]Height of base of stack (m)	Stack internal diameter at tip (m)	Exit velocity from stack (m/s)	Temperature (^{0}K)	NO_x emission rate as NO_2 (g/s)
1	Rolls Royce RB211	0	0	13.0	0	2.0	32.8	768.0	1.748
2	Taurus 60	0	0	13.0	0	2.0	15.6	783.0	0.548
3	Taurus 60	0	0	13.0	0	2.0	15.6	783.0	0.548
4	Meg	0	0	10.0	0	1.0	1.0	768.0	0.001
5	High/Low pressure flare	0	0	30.0	0	1.0	18.5	789.0	2.98
6	Essential Diesel Generator	0	0	9.0	0	0.25	55.3	768.0	2.98
7	Hot oil	0	0	12.0	0	1.0	15.0	785.0	0.001

[1] For the screening assessment the emissions sources have all been assumed to be co-located at the centre of the prediction grid (0 mE and 0 mN) and the height of the base of the stack has been taken to be 0 m.

The results of the modelling are presented in Section 8.3.4.

6.2.5 Other Associated Activities

Additional project-related facilities and works are to be undertaken which will have negligible air quality impacts. These include the following:

- Minor facilities to be installed at two existing well-sites on the Hides Ridge namely Wellpad A at Hides 4, Wellpad E at Hides 4.
- New wellpads A to G and new wells at Hides 4 namely A1, A2, B1, B2, C1, D1, F1, and G1.
- New wellpad A and B at the Angore Gas Field namely A1 and B1.
- New wellpads A, B and C and new wells at A1, A2, B1 and C1.
- Upgrading of roads along the complete RoW once pipeline construction and backfill is complete.
- Hides gathering system for the flow lines from each well on Hides Ridge to tie into a spineline.

6.2.6 Emissions from MEG Processing

Mono-ethylene glycol (MEG) is used to remove moisture from the gas. There will be emissions from the rich MEG tank as a result of diurnal heating and cooling of the tank and when the tanks are filled. This will result in emissions of benzene, toluene, ethyl benzene and xylene (BTEX) compounds from the tank's vent pipe at the top of the tank, approximately 5 m above local ground-level. Because these emissions are minor and any exceedences of assessment criteria would be expected to occur within a few tens to a few hundreds of metres from the emissions source these have been modelled using the Victorian EPA's Ausplume model in the same way as was done for the emissions at Juha.

The model was set up to make predictions on a square grid with sides of 1 km and with a grid spacing 50 m by 50 m. The emissions source was at the centre of the grid. A synthetic meteorological data set was used covering all possible meteorological conditions and the model was run to determine the maximum predicted 1-hour average concentrations of each of the BTEX compounds.

Daily tank heating from a mean daily minimum temperature of 13 ^oC to a mean daily maximum temperature of 24 ^oC will expand the volume by approximately 4% and will give an average emission due to expansion of tank vapour of 3 to 4 m^3/day. This will most likely occur during the first half of the daylight hours. It is estimated that typical daily releases from the MEG Tank will be approximately as follows:

- Year 1: 260 scfd
- Year 5: 230 scfd
- Year 6: 180 scfd
- Year 10: 450 scfd.

The assumed emissions for the worst-case (Year 10) were calculated from the above data and gave the following:

- Benzene – 0.000486 g/s
- Toluene – 0.000574 g/s
- Ethyl benzene – 0.00066 g/s
- Xylene – 0.000661 g/s.

The resulting ground level concentrations of these emissions have been assessed in Section 8.3.5, which provides information on the maximum 1-hour average ground-level concentrations likely to arise as a result of the emissions.

6.2.7 Emissions from augmented facilities

The PNG LNG Project will require augmentation of the facilities at Gobe, Kutubu and Agogo. The augmentation works will involve the installation of conventional Tri-ethylene Glycol (TEG) units to dry the natural gas before it is sent to the pipeline or used in other parts of the plants. In the process of regenerating the TEG, water vapour is driven off using heat. Some BTEX compounds are also driven off with the water vapour. Exxon's internal standards require that the water vapour with the associated BTEX be treated by thermal destruction or industry best practice so the majority of combustible BTEX compounds are destroyed before release to the atmosphere.

The purpose of this section of the report is to estimate the ground-level concentrations of BTEX compounds that would occur should the flare fail (and hence the incineration process fail) and BTEX emissions occur directly to the atmosphere.

This section provides a screening level assessment using the Gobe Production Facility (GPF) as an example.

At Gobe the HP flare is designed to deal with a gas load of 208,000 kg/h. The TEG unit is designed to handle 12 lb of H_2O/MMSCF, but recent plant data indicates that there is 13 to 14 lb H_2O/MMSCF of dry gas. Assuming a moisture content of 14 lb of H_2O/MMSCF (i.e. 225 kg/MMSCM) and a gas density of 0.9 kg/Nm^3 then 208,000 kg of gas will contain equivalent to 52 kg of water [(208,000 kg /

0.9 kg/m^3) x (225 kg / 1,000,000 m^3)]. If this is the maximum quantity of water captured per hour and if the TEG is regenerated at the same rate (as it must be used when dealing with a wet gas arriving at 208,000 kg/h) then the plant would discharge 52 kg of H_2O/h. Approximately 1% of the water vapour may be VOCs and so the VOC emission rate is estimated to be 0.144 g/s.

If the emission occurs through the flare tower at 30 m above local ground-level and through a vent with an internal diameter at the tip of 0.3 m and with an exit velocity of a nominal 1 m/s at ambient temperature, then the maximum 1-hour average ground-level concentration of VOC can be calculated using the Ausplume model and the same screening procedure described in Section 7.1 and 7.2. The results of this are presented in Section 8.3.6.

The hot exhaust gases from the flare will undergo rapid plume rise and not cause any perceptible heat effects at the ground. Radiant heat from the flare will be perceptible at ground level during flaring and will be managed through the use of buffer space.

6.2.8 Mitigating measures during operations

The following mitigation measures warrant consideration by the project during operations:

- BTEX emissions will be treated by thermal destruction or industry best practice.
- Low-NO_x emissions equipment will be fitted on the turbine generators and gas compressors.
- Diesel-powered equipment to be regularly serviced and diesel fuel quality standards with respect to sulphur levels will comply with local regulations.
- Fixed and mobile equipment (i.e., generators required for welding) will be located sensitively with respect to local people.

7 MODELLING METHODOLOGY

Not all parts of the PNG LNG Project have been designed to the same level of detail. For those elements where the design is advanced (e.g. the Hides Gas Conditioning Plant) the assessment has been undertaken using the CALMET/CALPUFF dispersion model (see next section). For elements of the project where the design is less well advanced the assessment has been undertaken using a screening approach based on the Ausplume dispersion model (Victorian EPA, 2000). The screening approach is likely to be more conservative than the CALMET/CALPUFF approach and may exaggerate the air quality effects of the emissions. Both methods are described below.

7.1 Preparation of meteorological data files

The proposed Hides Gas Conditioning Plant is in complex terrain at an elevation of approximately 1,700 m above mean sea-level. Winds would be expected to be significantly affected by the terrain at least until the plumes have risen to above the top of the Hides Ridge. Most regulatory models (e.g. the Ausplume model) assume Gaussian diffusion with the emissions transported in straight lines downwind from the point of emission. These would not be appropriate for assessing the emission sources at Hides, although the standard Gaussian models would be expected to simulate the dispersion close to sources (within a few hundred metres) with reasonable accuracy and can be used as a screening approach. Thus the use of a simple Gaussian model to simulate the dispersion of BTEX emissions and to assess the effects of emissions at the Juha Production Facility is reasonable.

The US EPA approved dispersion model CALMET/CALPUFF (version 5) (Scire et al., 2000A and Scire et al., 2000B) has been developed to deal with dispersion in complex flows, where the assumption that the winds flow in straight lines is not realistic. The CALMET/CALPUFF models are applied in a two-step process. Firstly, a meteorological data file is developed using the CALMET model. This file contains information on wind speed, wind direction, atmospheric stability, mixing height on a three-dimensional grid, in this case at points spaced 500 m apart in the horizontal and at nine levels in the vertical[9] and covering an area 20 km by 20 km with the southwest corner of the grid at Universal Transverse Mercator (UTM) coordinate 690250 mE and 9326250 mN (Zone 54S). The proposed Hides Gas Conditioning Plant is located at the approximate centre of this grid.

The wind information was developed by CALMET using output from the Commonwealth Scientific and Industrial Research Organisation's (CSIRO) prognostic model known as – The Air Pollution Model (TAPM). TAPM predicts local-scale meteorology, such as sea breezes, terrain induced flows and so on. It uses data from the Bureau of Meteorology's Global Analysis and Prediction (GASP) model. This feeds into the Limited Area Prediction System (LAPS) (Puri et al., 1997) which is used to provide meteorological predictions over 37 km grids. TAPM uses information such as terrain and sea breezes to adjust these data to provide meteorological data on a smaller scale. The model is discussed further in the user manual (Hurley, 2002). The TAPM model was used to generate winds at 10 m (above local ground-level) using data for 2006 at five locations with UTM (Zone 54S) coordinates at:

- 690000 mE and 9339000 mN (approximate location of the Hides Gas Conditioning Plant)
- 694000 mE and 9346000 mN
- 700000 mE and 9334000 mN
- 703000 mE and 9326000 mN
- 695000 mE and 9326000 mN.

In addition, TAPM was used to calculate wind and temperature profiles up to 2,500 m above local ground-level at the central site. These data were used as input into the CALMET model and with detailed terrain data for the area and information on land use. The model was then used to generate wind field data for use with the CALPUFF model.

In cases where the Ausplume model has been applied a synthetic meteorological data has been used. The synthetic data set is an hourly data file set (provided with the model) that essentially covers all possible dispersion conditions so that the model can identify the highest possible ground-level concentration of emissions that can theoretically arise regardless as to whether or not such dispersion conditions can occur, or are likely to occur, in an area. When using the Ausplume model in this conservative screening mode the emission sources have been co-located to ensure that the worst-case scenario is assessed.

7.2 Dispersion

CALPUFF simulates the emission as a series of overlapping puffs that are assumed to be released from the source in a way that approximates a continuous plume. The diffusion and movement of each puff is controlled by the information contained in the meteorological file generated by CALMET, which specifies the wind speed, wind direction and dispersive properties of the atmosphere, for each hour of the year, at the three-dimensional grid discussed above.

[9] Levels used in the model were the mid points between 0, 20, 50, 100, 200, 400, 800, 1600, 2000 and 2500 m above ground-level.

The Ausplume model assumes that for each hour, emissions are instantaneously transported from the point of emission to the edge of the prediction grid. Ground-level concentrations are calculated by assuming the plume disperses in the horizontal and vertical according to the Pasquill dispersion curves for the prevailing meteorological conditions (see Victorian EPA, 2000).

7.3 Modelling dispersion of NO_x

At the point of emission between 5 and 10% of the NO_x emission will be in the form of NO_2 and the remainder will be in the form of the less harmful NO. Over time NO is oxidised to NO_2 and later to nitrates. The rate of oxidation depends on the concentration of oxidants in the atmosphere, primarily on the concentration of ozone (O_3).

The assessment is undertaken by comparing the concentrations of NO_2, rather than NO_x with the assessment criteria.

In the lower atmosphere, O_3 occurs in part because of transport downwards from the upper atmosphere (the ozone layer), but more usually, from photochemical reactions that take place between hydrocarbons and nitrogen oxides in the presence of sunlight. These reactions are the predominant source of O_3 in large urban areas, where emissions from motor vehicles, industrial sources and other sources of reactive hydrocarbon and NO_x can give rise to significant O_3 concentrations on the outskirts of large cities.

The US EPA has developed a procedure known as the ozone limiting method (OLM) which allows a conservative estimate of the NO_2 concentration to be made in a NO_x plume. The calculation requires knowledge of the background O_3 concentration, which is usually derived from direct measurements. Such data are readily available in urban areas where the method is mostly used. For this study it has been assumed that O_3 concentrations will be in the range 20 to 40 ppb (43 to 86 $\mu g/m^3$), which is the range quoted by Seinfeld and Pandis (1998) for remote areas.

The OLM method can be summarised by the following equation:

$$[NO_2]_{total} = \{0.1 \times [NO_x]_{predicted}\} + \text{minimum of } \{0.9 \times [NO_x]_{predicted} \text{ or } (46/48) \times [O_3]_{background}\} + [NO_2]_{background}.$$

Where,

$[NO_2]_{total}$ = the predicted concentration of NO_2, via OLM, in $\mu g/m^3$,
$[NO_2]_{predicted}$ = the predicted concentration of NO_2 in $\mu g/m^3$ from the dispersion model in $\mu g/m^3$,
$[O_3]_{background}$ = the background concentration of O_3 in $\mu g/m^3$,
46/48 = the molecular weight of NO_2 divided by the molecular weight of O_3, and
$[NO_2]_{background}$ = the background concentration of NO_2 in $\mu g/m^3$.

If the $[O_3]_{background}$ is taken to be 86 $\mu g/m^3$ (the upper end of the range suggested by Seinfeld and Pandis) and $[NO_2]_{background}$ is taken to be zero (since there are no significant sources of NO_2 present in the area apart from those included in the model) then the value of NO_2 is estimated to be 10% of the predicted concentration of NO_x plus the minimum of 90% of the predicted NO_x concentration or 82 $\mu g/m^3$. (Note, 82 = 86 x (45/48)).

8 ASSESSMENT OF EFFECTS

8.1 Preamble

The project involves a number of different activities that require assessment at different levels of detail. The impacts arising from various construction activities, namely site works at the original Hides Gas Plant and works at Kutubu as well as the works required for construction of the pipeline were assessed in the Gas Project EA (Holmes Air Sciences, 2005). The major emissions from these works will be fugitive dust and exhaust from diesel-powered earthmoving equipment. Although the site works required for the Hides Gas Conditioning Plant envisaged for the PNG LNG Project will be larger than for the PNG Gas Project and in a different location and the works would extend over a longer period estimated to be approximately 12 months, and dust concentrations (i.e. impacts) would be similar.

The potential impacts of emissions from gas-fired compressors, power generation equipment, etc involves issues that are not as easy to relate to everyday experience. These have been assessed using dispersion models to predict ground-level concentrations of emissions, which have then been compared with the internationally recognised assessment criteria (see Section 3).

In practice, because of the very low sulphur content of the fuels and the very low particulate matter and CO emissions associated with burning natural gas as fuel the only pollutant that has required a detailed assessment is nitrogen dioxide during the operational phase.

The fact that CO emissions will comply with the relevant assessment criteria can be determined by noting that the emissions of CO are in every case much less than emissions of NO_x and the assessment criterion for 1-hour CO concentrations is 30,000 $\mu g/m^3$ compared with the 1-hour average assessment criterion for NO_2 which is 200 $\mu g/m^3$.

The fact that SO_2 emissions will also comply can be seen by examining the estimated emission rates for SO_2 and noting that they are of the order of 500 times less than the emissions of NO_2 for any given item of plant, while the compliance standard is similar to that for NO_2.

VOC emissions will arise from a variety of sources including leaks, spills, incomplete combustion of flare gases, and the glycol regeneration plant and from tank venting. The BTEX emissions from the glycol regeneration process will be disposed of in the flare, but there will still be some residual emission. Emissions from these sources cannot be reliably quantified and thus cannot be assessed using a dispersion model. These will be managed to ensure that concentrations do not exceed the assessment guidelines at the closest non-company owned property by monitoring. The project should consider monitoring on a campaign basis following commissioning and a year after and, assuming that the measured concentrations are well below the TNRCC ESLs, then only when there is a reason to believe that emissions of BTEX compounds might have changed.

8.2 Construction

8.2.1 Pipeline

Construction of the PNG land portion of the pipeline will be done over a three-year period. It will involve firstly clearing vegetation from the route which will create a corridor approximately 30 m wide depending on the terrain. When the advance clearing work has been completed, overburden will be removed and stockpiled on one side, the pipeline trench will be excavated and a service road will be constructed. The pipeline string will be assembled by welding sections on the surface beside the trench. The welded pipeline will be placed in the trench using bulldozers fitted with side booms.

The final stage will involve burying the pipeline and reinstating the surface so that vegetation can grow and the surface stabilised against the effects of erosion. While the scale of the operation will be large, involving five to six hundred workers per spread and of the order of 200 machines, the works will be spread out and will progress on average approximately 250 m/day. This will ensure that the disturbances at any particular location are only temporary.

Most of this construction work will take place in remote areas. For short periods the active working area will pass close to villages or other settlements. When this occurs the main issue will be to control dust generated by earthmoving equipment and emissions of diesel exhausts. Simple controls such as those listed in Section 6.1.5 will be used to manage the emissions of dust and exhausts from construction equipment.

8.2.2 Construction of well pads and drilling

The effects of dust emissions from construction were discussed in Section 6.1.2. The effects of emissions of exhaust gases from drilling equipment have been assessed using a screening procedure using the Ausplume model, the estimated emissions provided in **Table 2** and a wide range of dispersion conditions, including the worst-case. The predicted maximum 1-hour average ground-level concentrations were as follows:

- Nitrogen dioxide – 139 µg/m^3
- Carbon monoxide – 149 µg/m^3
- VOCs - 14 µg/m^3
- PM_{10}- 17 µg/m^3
- $PM_{2.5}$ – 17 µg/m^3.

The US EPA's ozone limiting method has been used in the calculation of 1-hour average nitrogen dioxide concentrations.

The construction periods for the well pads will be of limited duration, less than one year, so assessment against long term assessment criteria is not appropriate. The predicted concentrations for nitrogen dioxide and carbon monoxide are all below the assessment criteria for these substances. The predicted VOC concentration is less the benzene criterion and since benzene has the most stringent concentration limit the concentrations would also be below the criteria for the other BTEX compounds.

Finally the PM_{10} and $PM_{2.5}$ assessment criteria are related to 24-hour averaging periods but 1-hour average concentrations will always be higher than 24-hour average concentrations so a 1-hour concentration that complies with the 24-hour assessment criterion implies that the 24-hour average will comply with the 24-hour average assessment criterion. Thus the screening assessment shows that if the exhaust emissions are released from appropriately designed exhaust systems they will not cause air quality assessment criteria to be exceeded at any settlements.

Camp sites supporting the drilling operation will also operate diesel generators that will typically consume 1,000 litres of diesel per day. Again appropriately sized exhausts fitted to the generators will be used to disperse these emissions.

Other mitigating measures are described in Section 6.1.5.

8.2.3 Construction at the Hides Gas Conditioning Plant

Construction of the Hides Gas Conditioning Plant will involve site works in a greenfield area within the 75 ha fenced area. Site preparation works will take place over approximately 12 months followed by construction of buildings, foundations and installation of gas plant equipment over a further 32 month period.

The effects of emissions of TSP and PM_{10} have been modelled assuming that the construction site consists of 40 ha of disturbed ground and applying the US EPA single factor emission factor of 2.69 t/month of TSP (see Section 6.1.4).

Figures 5 and 6 show the predicted 24-hour and annual average TSP concentrations respectively due to construction activities required for the Hides Gas Conditioning Plant. The figures also show the assessment criteria suggested by the WHO (1987). The predictions show that emissions from the construction activities in isolation would not cause the WHO criterion to be exceeded for residences located outside the proposed plant fenced area. Background PM_{10} levels have not been measured in this area, but based on local land use are estimated to be less than 20 $\mu g/m^3$ (annual average) and less than 30 to 40 $\mu g/m^3$ (24-hour average) except when affected by smoke from fires. It is unlikely that the combined effects of the background plus emissions from the earthwork would reach levels where exceedances could occur at nearby dwellings beyond the proposed fence line.

Figures 7 and 8 show the predicted 24-hour and annual average PM_{10} concentrations respectively due to the construction activities required for the Hides Gas Conditioning Plant. The figures also show the guidelines (Interim level 1) suggested by the WHO (2005). Again the predictions show that emissions from the construction activities in isolation would not cause the WHO criterion to be exceeded for residences beyond the proposed plant fenced area. Also background levels would be unlikely to reach levels where exceedances could occur.

Figures 9 and 10 show the predicted 24-hour and annual average $PM_{2.5}$ concentrations respectively due to the Hides Gas Conditioning Plant construction activities. Again the figures also show the guidelines (Interim level 1) suggested by the WHO (2005). The predictions show that emissions from the construction activities in isolation would not cause the WHO criterion to be exceeded for residences beyond the plant fenced area. Also background levels would be unlikely to reach levels where exceedances could occur.

It is understood that residences currently located on the site will be relocated.

Standard mitigating measures in relation to construction are described in Section 6.1.5.

8.3 Operations

This section assesses the impacts of emissions associated with the operational phase of the project and includes an analysis of the project considered in isolation and considered in conjunction with existing operations namely the Porgera Power Station and the adjacent gas plant at Hides.

8.3.1 Existing Hides Gas Plant

In practice, there are no significant emissions from the existing gas plant at Hides. However, cumulative effects due to combined emissions from the Porgera Power Station and the proposed Hides Gas Conditioning Plant need to be assessed. This is done in the next section.

8.3.2 Hides Gas Conditioning Plant

Estimated ground-level concentrations of NO_2 due to emissions from the proposed Hides Gas Conditioning Plant Stage 2 have been made using the CALPUFF model and the emissions detailed in **Table 4**. The OLM has been used to account for the conversion of NO to NO_2.

Figure 11 shows the maximum predicted 1-hour average NO_2 concentrations due to emissions from the Hides Gas Conditioning Plant assuming that emissions are appropriate for Stage 2 operations i.e. the emissions from the two additional booster compressors (planned to be installed in Year 6) are included. This gives rise to a worst-case emissions scenario. The highest concentrations predicted are less than 120 µg/m^3 which is less than the most stringent of the 1-hour average assessment criteria (200 µg/m^3). Given that the Stage 2 emissions comply with the assessment criteria there is no need to separately assess Stage 1, although it is still necessary to verify that cumulative concentrations comply with the assessment criteria when the cumulative effects of emissions from the Porgera Power Station are taken into account. This is done in Section 8.3.3.

Figure 12 shows the predicted annual average NO_2 concentrations due to the same emissions as above. The predicted concentrations show peak values less than 25 µg/m^3 in an area located approximately 2 km to the south-southeast of the Hides Gas Conditioning Plant. This is below the assessment criterion of 40 µg/m^3.

8.3.3 Cumulative Effects of Porgera Power Station at Hides and Hides Gas Conditioning Plant

The CALPUFF model and the emissions detailed in **Table 3** and **Table 4** have been used to predict the ambient concentrations of NO_2 arising from the Porgera Power Station and the Hides Gas Conditioning Plant. As before, the OLM model has been used to account for the conversion of NO to NO_2.

A simple analysis of how plumes from two separated sources can combine in the short term (in this case a 1-hour averaging period) will suggest what might be expected. Firstly, concentrations in the area between the two sources are unlikely to be affected because this would require the winds to blow in two directions at the same time. Higher concentrations are likely to occur when the wind is such as to blow emissions from one source over the other source so that areas that are downwind of both sources experience the enhanced concentrations due to the overlapping plumes. In this case the two emission sources are on a line running approximately north-northwest to south-southeast. The two plumes can only combine in areas to the north-northwest of the Porgera Power Station and to the south-southeast of the Hides Gas Conditioning Plant.

The modelling domain does not extend to areas north of the Porgera Power Station because the concentrations due to the Hides Gas Conditioning Plant are too low to be of interest (see Figure 13) There is no evidence that there is a significant cumulative effect to the south-southeast of the Hides Gas Conditioning Plant (see Figure 14), but the effects of the Porgera Power Station plume are clearly shown in the area to the southeast and east of the Hides Gas Conditioning Plant.

The maximum predicted 1-hour average NO_2 concentration at the most affected settlements remain well below the 200 µg/m^3 assessment criterion even after the cumulative effects of emissions from the Porgera Power Station area are included.

Figure 14 shows the predicted annual average NO_2 concentrations due to emissions from the existing Porgera Power Station and Hides Gas Conditioning Plant. Unlike the case for short-term average concentrations, annual average concentrations can experience an increase due to cumulative effects when a receptor is affected by a plume from one source on one occasion and later by a plume from another source. The plumes do not have to be in the same place at the same time. The annual average concentrations can increase simply because a receptor experiences the effects from both sources, albeit at different times over the year. This leads to a higher average concentration than if only one source was present. There is some evidence that this has a weak effect in the area to the north, east and south of the Hides Gas Conditioning Plant, but the annual average concentrations remain well below the assessment criterion of 40 µg/m^3.

8.3.4 Juha Production Facility

The predicted maximum 1-hour average ground-level concentration of NO_2 resulting from the emissions at the Juha Production Facility (including all sources shown in **Table 5**) was 84.0 µg/m^3. This was the highest predicted 1-hour average concentration predicted on a 2 km by 2 km grid with the centre of the Juha Production Facility located at the centre of the grid. The grid spacing was 100 m. The value of 84.0 µg/m^3 was also based on the assumption that 100% of the NO_x has been converted to NO_2. As discussed in Section 7.3, the maximum 1-hour average NO_2 concentration is taken to be 10% of the predicted concentration of NO_x plus the minimum of 90% of the predicted NO_x concentration or 82 µg/m^3. This gives a value of 84 µg/m^3. This is below the 200 µg/m^3 1-hour average WHO (2005) guideline.

Annual average concentrations depend on the variations in dispersion conditions, in particular in the variability in wind direction over the year. The screening approach, which uses synthetic meteorological data, is therefore not able to make predictions as to the likely annual average concentrations. However Section 8.3.2, which uses the site specific meteorological data for the Hides area indicates that annual average concentrations are likely to be approximately a factor of 5 (120/25 = 4.8) less than the maximum 1-hour average concentrations.

(Note this ratio is consistent with the relationship suggested by Turner (1994), that specifies the relationship between a pollutant concentration (C_{t1}) measured over time-interval t_1 will be related to the concentration (C_{t2}) measured over time-interval t_2 by the following:

$C_{t1} = C_{t2} \times (t_2 / t_1)^{0.2}$.

For t_1 equal to 1-hour and t_2 equal to 1-year (8,760 hours), $(t_2 / t_1)^{0.2}$ is equal to 6.1.

Assuming that the ratio at Juha is the same as at Hides, namely 5, then the annual average NO_2 concentration at Juha is estimated to be 17 µg/m^3 (17 = 84 / 5). This is below the WHO (2005) annual guideline for NO_2 of 40 µg/m^3.

8.3.5 MEG Tank Emissions

The predicted concentrations of emissions from the MEG tank have been modelled using the AUPLUME model assuming worst-case emissions (see Section 6.2.6).

The maximum predicted 1-hour average concentrations (under the least favourable dispersion conditions) on the modelling grid for each of the BTEX compounds were:

- Benzene - 3.91 µg/m^3
- Ethyl benzene – 5.32 µg/m^3
- Toluene - 4.62 µg/m^3
- Xylene - 5.32 µg/m^3.

These concentrations are all well below the assessment criteria discussed in Section 3.1.5. Note some of the compounds also have 24-hour or annual average assessment criteria but the predicted 1-hour concentrations are so low that there is no requirement to assess the emission against the standards for the longer term averaging periods.

8.3.6 Augmentation of facilities

The predicted concentrations of VOC emissions from the TEG unit when the incineration system fails and emissions are released untreated from the flare stack have been modelled using the AUPLUME model assuming the emissions levels estimated for a gas production level of 208,000 kg/h which would yield a VOC emission of 0.144 g/s if the incineration system failed (see Section 6.2.7).

The maximum predicted 1-hour average concentrations (under the least favourable dispersion conditions) on the modelling grid for a VOC emission rate of each 0.144 g/s was 14 $\mu g/m^3$.

This can be compared with assessment criteria for BTEX compounds (see Section 3.1.5). Since operation in a failure mode would not be expected to be allowed to persist for extended periods the comparison has only been done against the concentration limits for the short-term averages. Benzene is the substance with the lowest concentration limits and the assessment criterion is 170 $\mu g/m^3$ (1-hour average). Since the highest predicted 1-hour average VOC concentration was 14 $\mu g/m^3$ and this is less that 170 $\mu g/m^3$, it can be concluded that even if all the VOC emissions was comprised of benzene, the most harmful of the BTEX compounds, the assessment criterion would not be exceeded.

Thus emissions of VOCs from the TEG units are not predicted to cause the assessment criteria for BTEX compounds to be exceeded even if the incineration system where to fail.

8.4 Miscellaneous activities

Wellheads will require electrical power which will be supplied by small diesel generators. Emissions from these will be dispersed using appropriately designed exhaust systems. The emissions will be too small to justify inclusion of these in the dispersion modelling.

Standard mitigating measures in relation to operations are described in Section 6.2.8.

9 CONCLUSIONS

This report has analysed the air quality impacts associated with a project to construct and operate a gas pipeline to transport natural gas from gas fields in the Southern Highlands and Western provinces of PNG to an LNG Plant to be developed at Caution Bay approximately 20 km northwest of Port Moresby.

The assessment refers to an earlier assessment for the PNG Gas Project and concludes that impacts associated with dust emissions from construction work associated with the pipeline construction will be temporary and easily controlled to acceptable levels using standard industry control techniques including water carts and the maintenance of appropriate separation distances between construction areas and dust sensitive receptors.

As with all the construction activity, involving significant earthworks dust emissions from construction areas such as the Hides Gas Conditioning Plant have the potential to cause the air quality assessment criteria for TSP and PM_{10} to be exceeded while work is in progress however provided these works will be managed carefully using simple measures as described in Section 6.1.5 it will be possible to maintain air quality at levels that comply with the WHO assessment criteria at dwellings beyond the proposed fence line.

The project will require the use of gas-fired turbines to operate compressors and power generation units and the use of flares to dispose of excess gas from time to time. Computer-based dispersion modelling shows that the ground-level concentrations of NO_2 associated with NO_x emissions from the activities will comply with internationally recognised assessment criteria. This conclusion is also true when the cumulative effects of emissions from existing sources of NO_x in the area are taken into account.

Emissions of PM_{10}, CO and SO_2 are too small to justify an assessment via dispersion modelling, but these will also comply with internationally recognised assessment criteria by significant margins.

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FIGURES

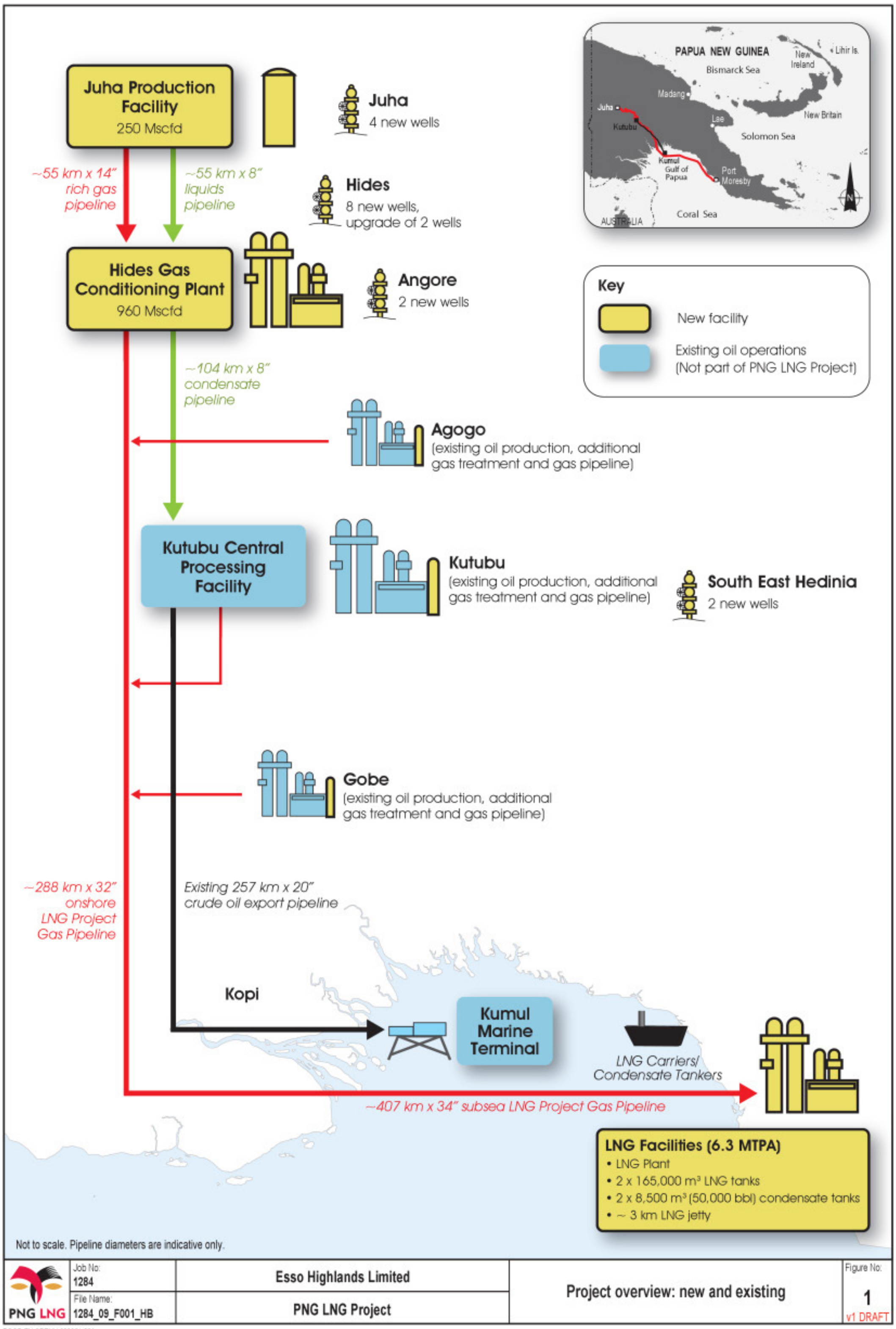

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Figure 1

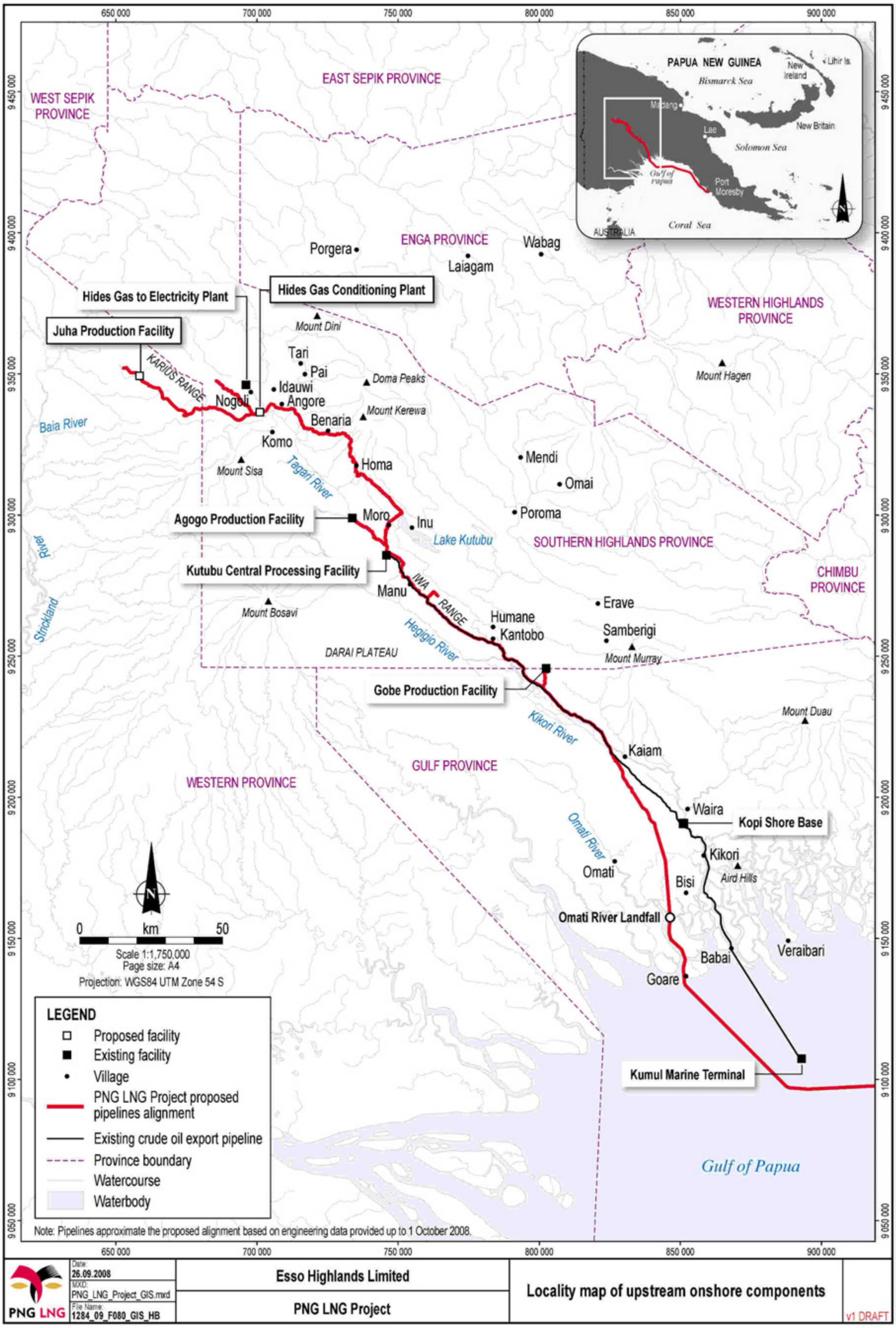

EAST SEPIK PROVINCE
WEST SEPIK PROVINCE
ENGA PROVINCE
WESTERN HIGHLANDS PROVINCE
SOUTHERN HIGHLANDS PROVINCE
CHIMBU PROVINCE
WESTERN PROVINCE
GULF PROVINCE
PAPUA NEW GUINEA
Bismarck Sea
Solomon Sea
Coral Sea
New Ireland
New Britain
Lihir Is.
Madang
Lae
Port Moresby
Gulf of Papua
AUSTRALIA
Hides Gas to Electricity Plant
Hides Gas Conditioning Plant
Juha Production Facility
Agogo Production Facility
Kutubu Central Processing Facility
Gobe Production Facility
Kopi Shore Base
Omati River Landfall
Kumul Marine Terminal
Porgera
Laiagam
Wabag
Mount Dini
Tari
Pai
Idauwi
Angore
Nogoli
Benaria
Komo
Doma Peaks
Mount Kerewa
Mount Sisa
Homa
Mendi
Omai
Poroma
Moro
Inu
Lake Kutubu
Manu
IWA RANGE
KARIUS RANGE
Mount Bosavi
Humane
Kantobo
Erave
Samberigi
Mount Murray
DARAI PLATEAU
Mount Hagen
Mount Duau
Kaiam
Waira
Kikori
Aird Hills
Bisi
Omati
Babai
Veraibari
Goare
Baia River
Tagari River
Strickland River
Hegigio River
Kikori River
Omati River
Gulf of Papua
0 km 50
Scale 1:1,750,000
Page size: A4
Projection: WGS84 UTM Zone 54 S
LEGEND
Proposed facility
Existing facility
Village
PNG LNG Project proposed pipelines alignment
Existing crude oil export pipeline
Province boundary
Watercourse
Waterbody
Note: Pipelines approximate the proposed alignment based on engineering data provided up to 1 October 2008.
Date: 26.09.2008
MXD: PNG_LNG_Project_GIS.mxd
File Name: 1284_09_F080_GIS_HB
PNG LNG
Esso Highlands Limited
PNG LNG Project
Locality map of upstream onshore components
v1 DRAFT

Figure 2

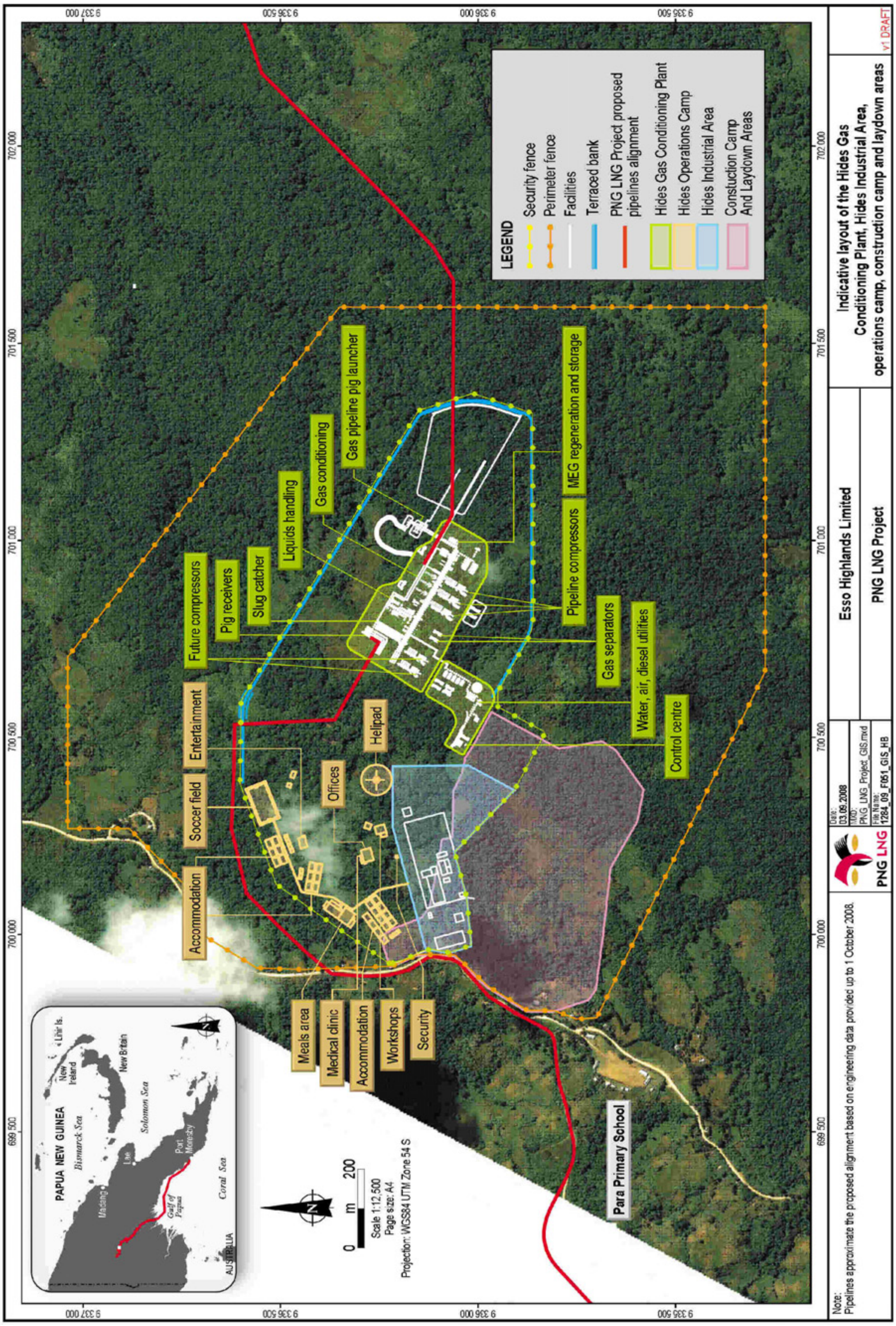
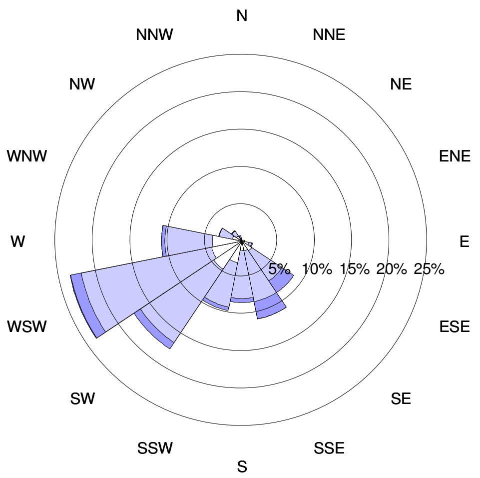

Indicative layout of the Hides Gas Conditioning Plant, Hides Industrial Area, operations camp, construction camp and laydown areas
Esso Highlands Limited
PNG LNG Project
LEGEND
Security fence
Perimeter fence
Facilities
Terraced bank
PNG LNG Project proposed pipelines alignment
Hides Gas Conditioning Plant
Hides Operations Camp
Hides Industrial Area
Constuction Camp And Laydown Areas
Accommodation
Soccer field
Entertainment
Offices
Helipad
Future compressors
Pig receivers
Slug catcher
Liquids handling
Gas conditioning
Gas pipeline pig launcher
MEG regeneration and storage
Pipeline compressors
Gas separators
Water, air, diesel utilities
Control centre
Meals area
Medical clinic
Accommodation
Workshops
Security
Para Primary School
PAPUA NEW GUINEA
Bismarck Sea
Solomon Sea
Coral Sea
Gulf of Papua
Madang
Lae
Port Moresby
New Ireland
New Britain
Lihir Is.
AUSTRALIA
Scale 1:12,500
Page size: A4
Projection: WGS84 UTM Zone 54 S
Note:
Pipelines approximate the proposed alignment based on engineering data provided up to 1 October 2008.
PNG LNG
Date: 03.09.2008
File Name: 1284_09_F051_GIS_HB
v1 DRAFT
PGGP-EN-SPENV-000001-001
RevA

Figure 3

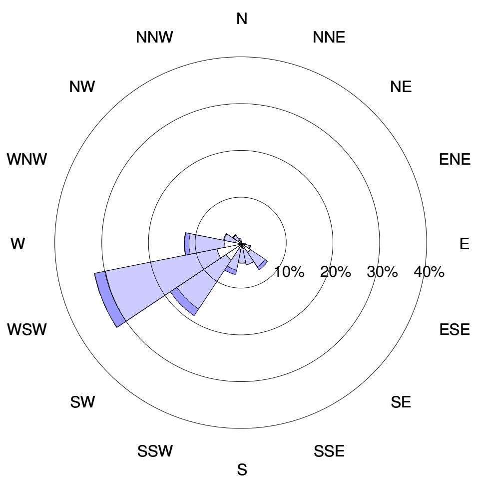
Annual and seasonal windroses for PNG (Hide Gas Conditioning Plant site Lat 6.000 South, 142.8167 North) 2006

Wind speed (m/s)

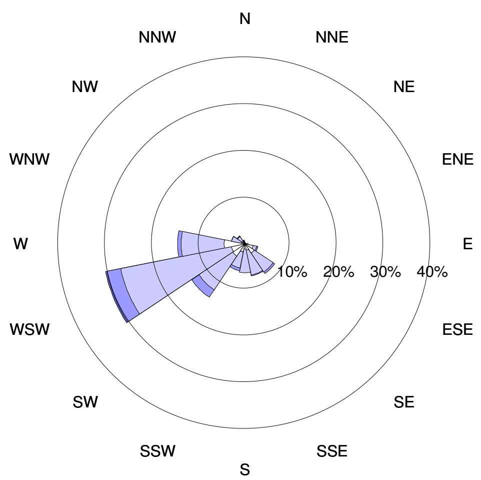
- >0.5 - 1.5
- >1.5 - 3
- >3 - 4.5
- >4.5 - 6
- >6 - 7.5
- >7.5



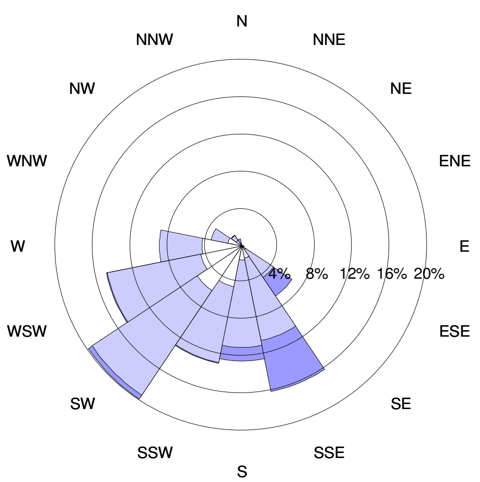
Annual
Calms = 4.0%



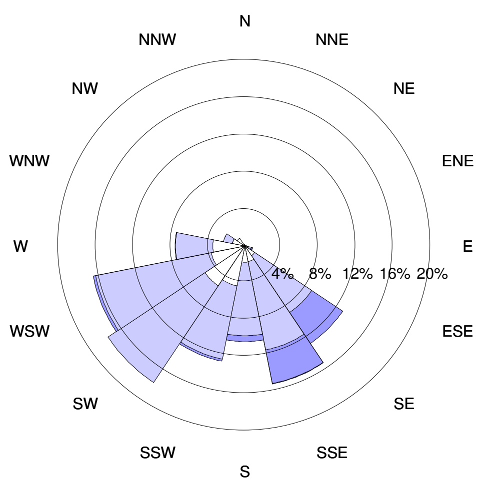
Summer
Calms = 4.5%



Autumn
Calms = 5.0%

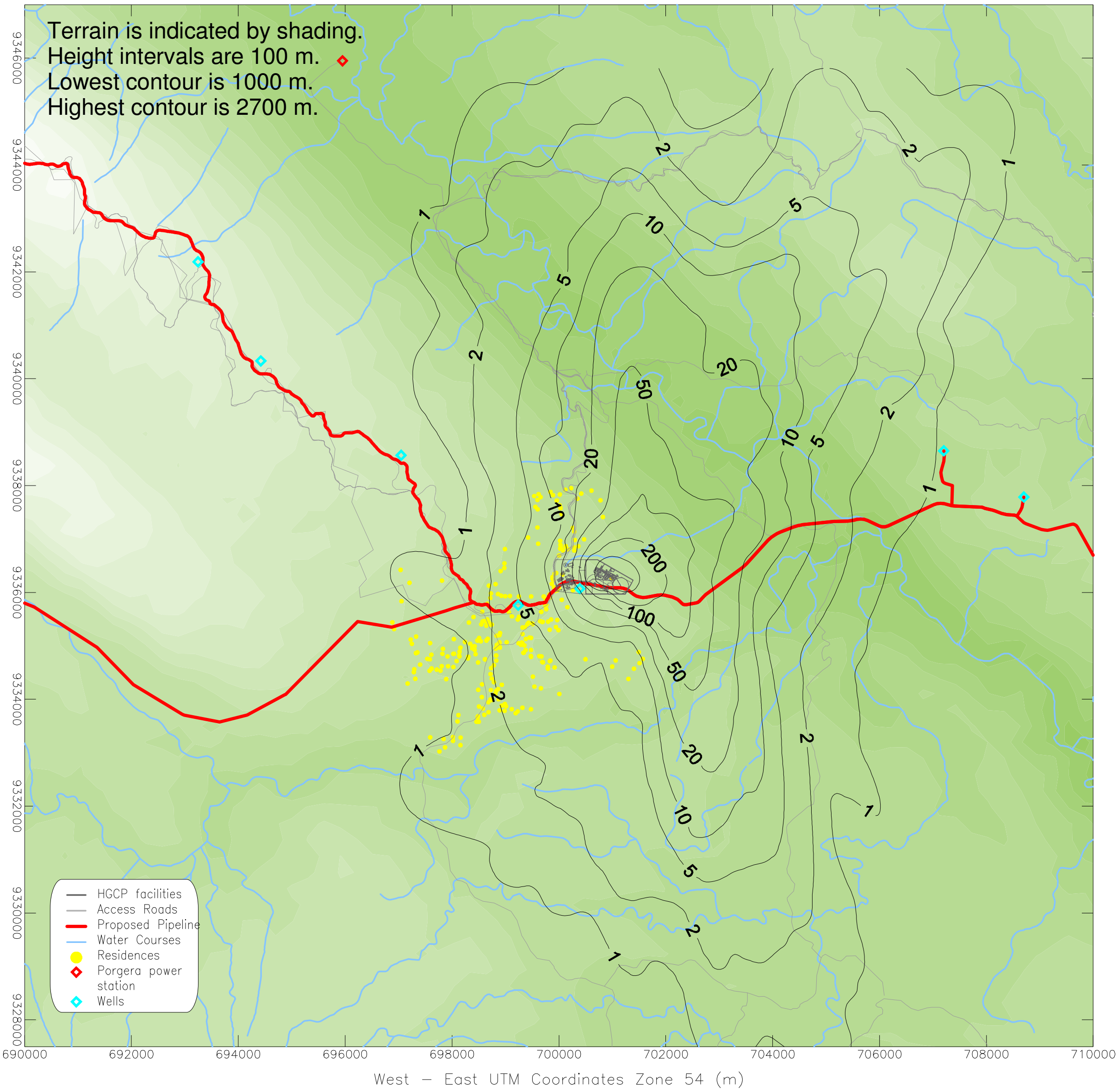


Winter
Calms = 3.2%



Spring
Calms = 3.3%

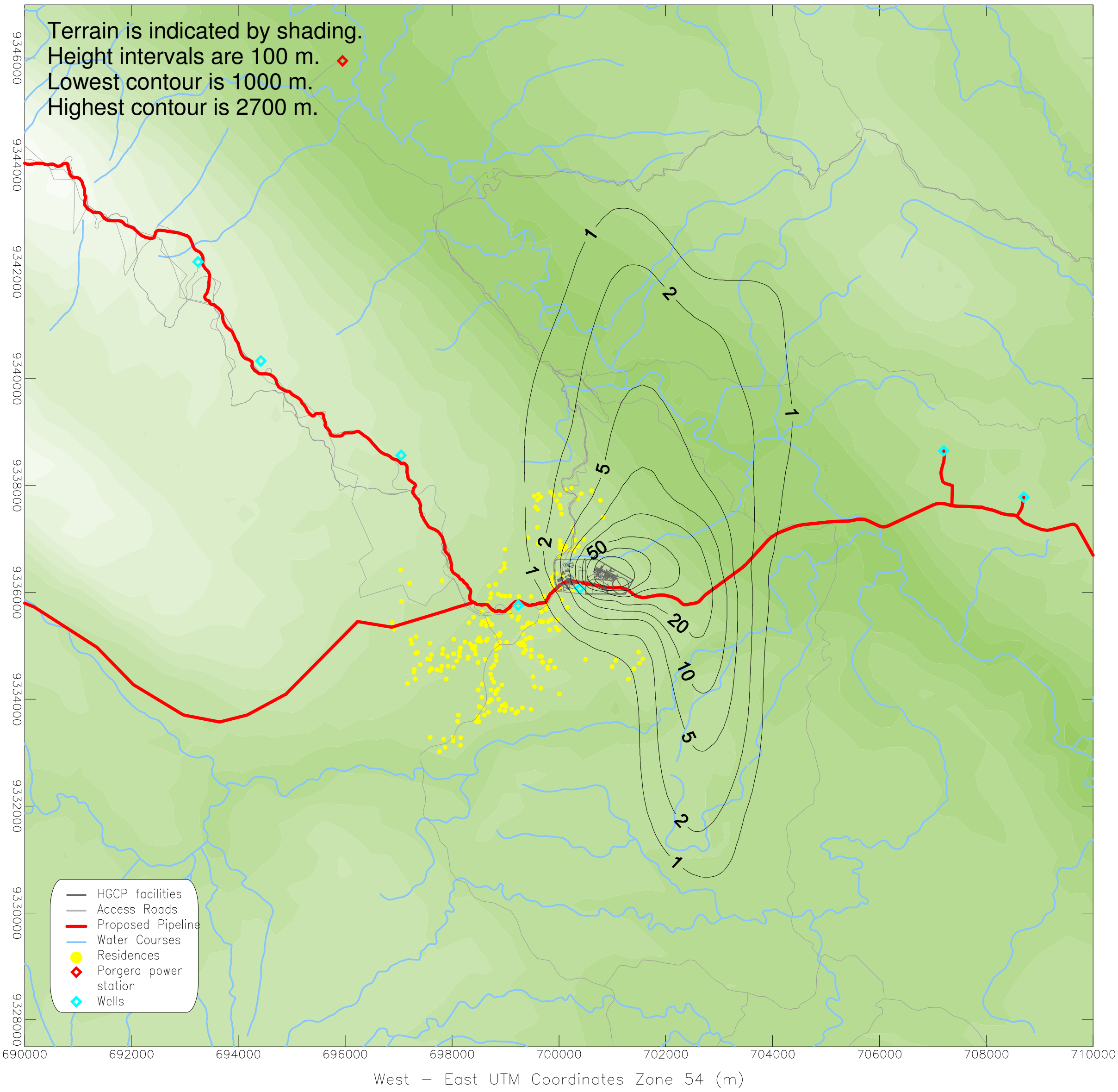
Figure 4



WHO (1987) 24-h assessment criterion is 150 to 230 µg/m^3

Predicted 24-hour average TSP concentrations due to emissions from the construction of the Hides Gas Conditioning Plant (see text) - µg/m^3

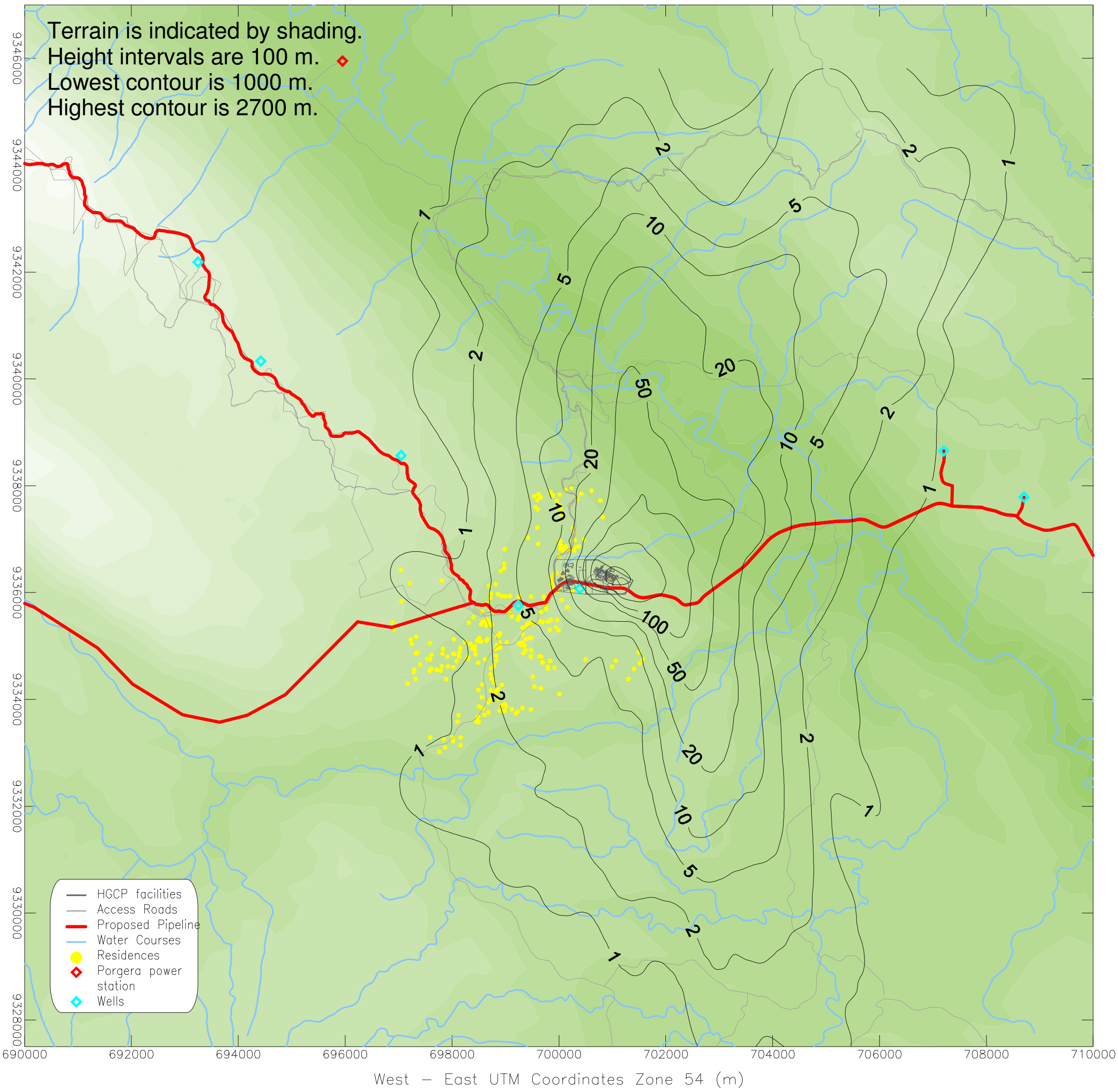
Figure 5



WHO (1987) annual TSP assessment criterion is 60 to 90 µg/m^3

Predicted annual average TSP concentrations due to emissions
from the construction of the Hides Gas Conditioning Plant (see text) - µg/m^3

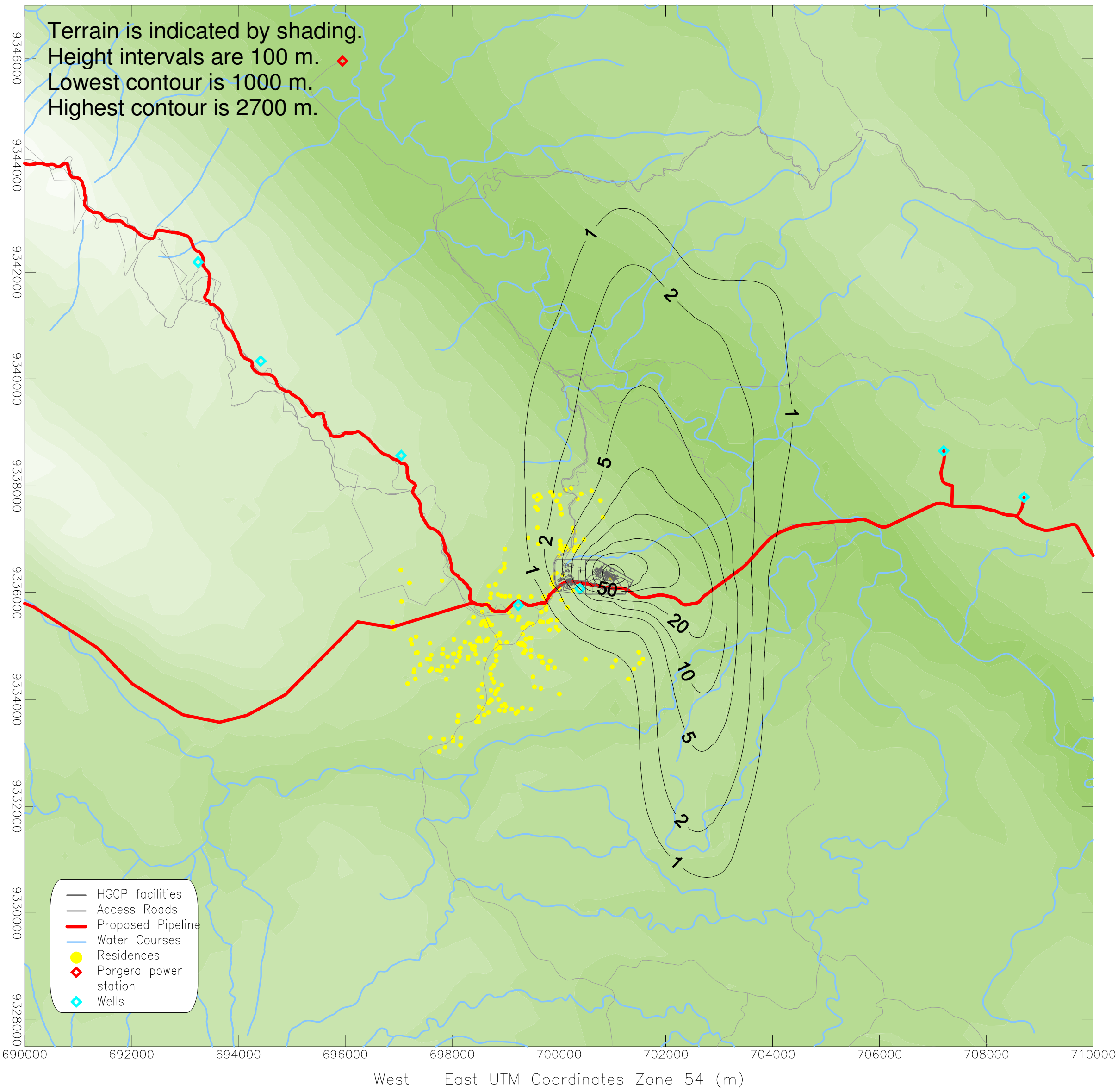
Figure 6



WHO (2005) (Interim target 1) 24-h guideline for PM_{10} is 150 µg/m^3

Predicted 24-hour average PM_{10} concentrations due to emissions
from the construction of the Hides Gas Conditioning Plant (see text) - µg/m^3

Figure 7

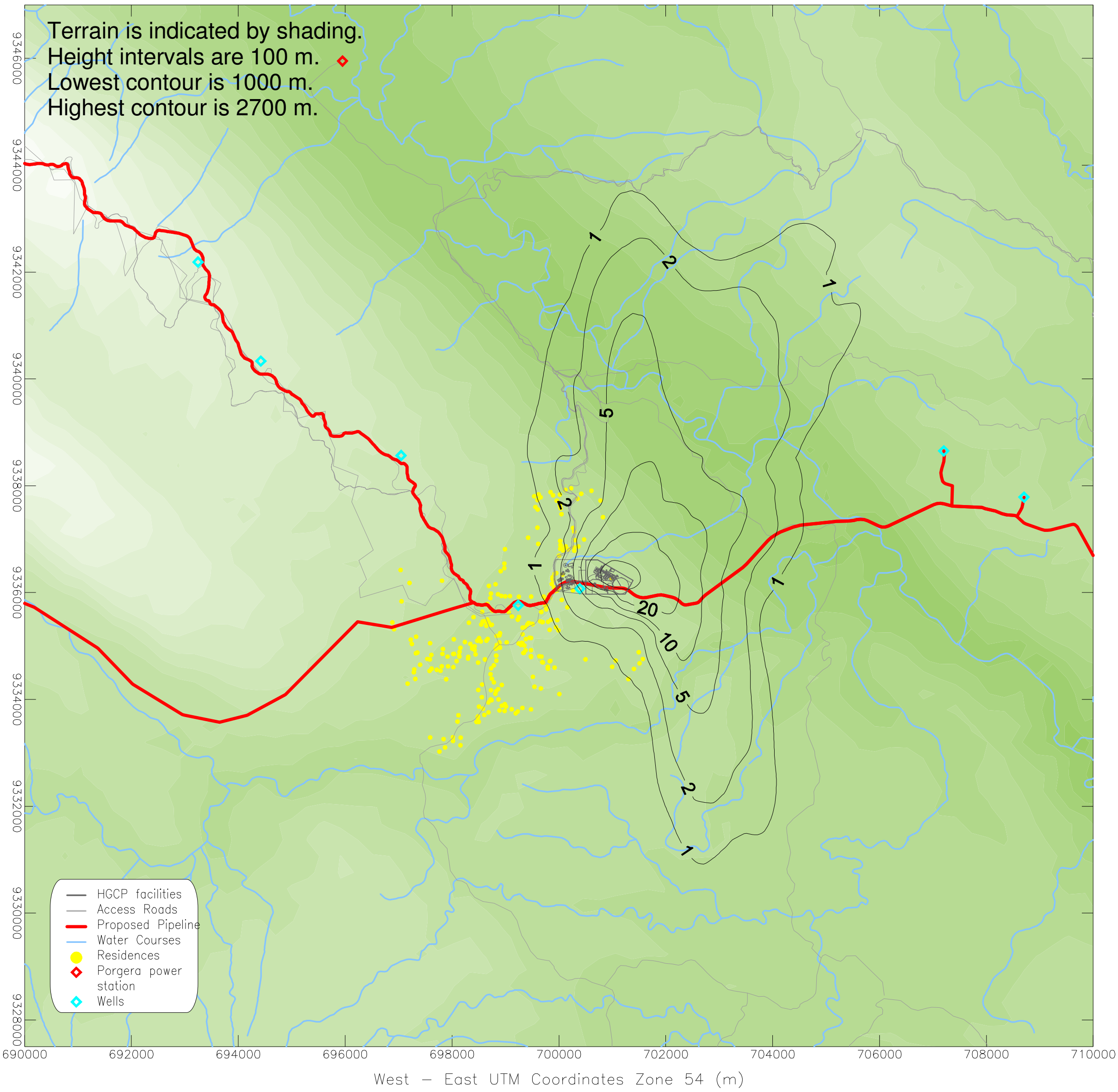


WHO (2005) (Interim target 1) annual guideline for PM_{10} is 150 µg/m^3

Predicted annual average PM_{10} concentrations due to emissions

from the construction of the Hides Gas Conditioning Plant (see text) - µg/m^3

Figure 8

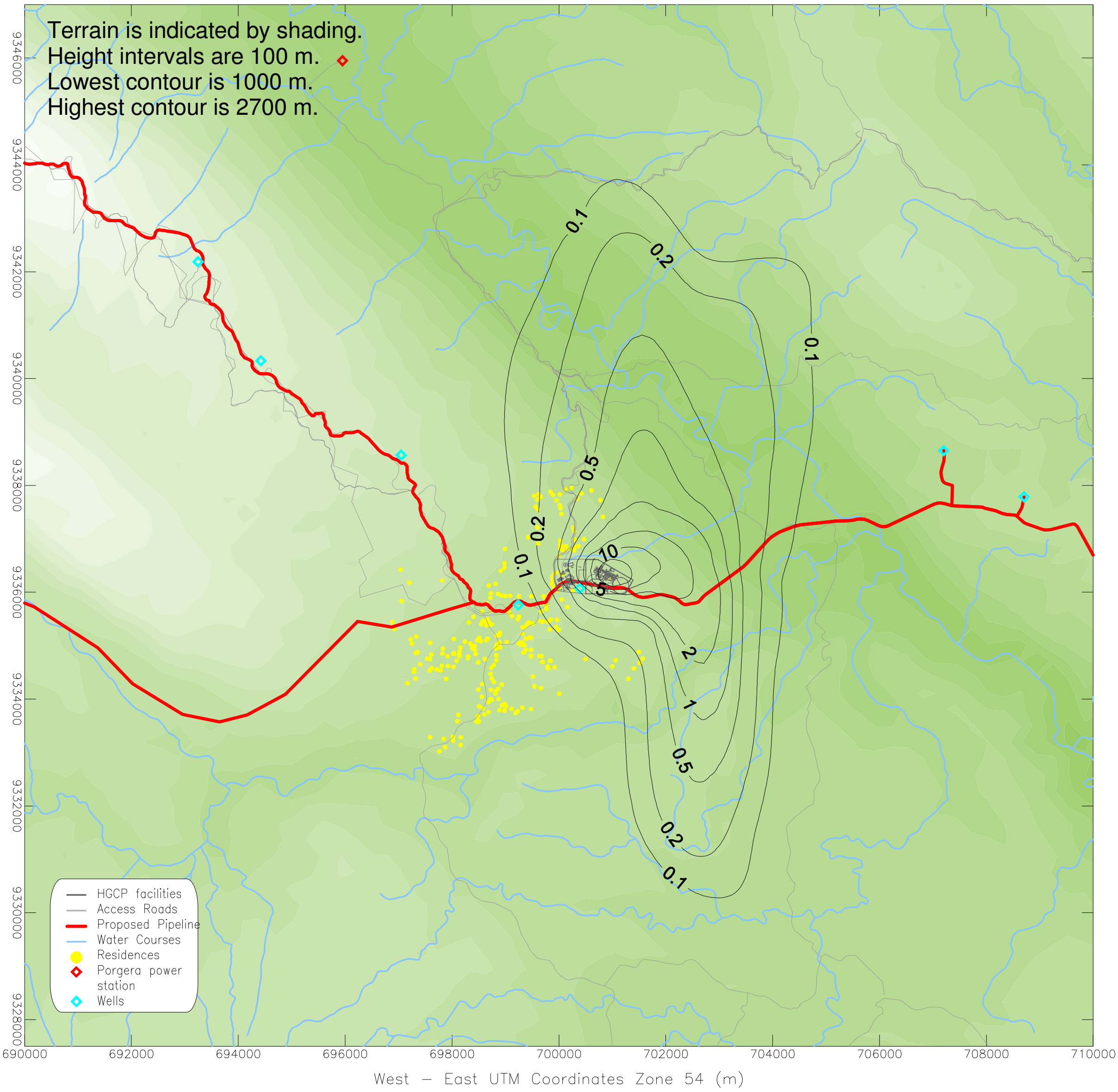


WHO (2005) (Interim target 1) 24-hour guideline for $PM_{2.5}$ is 75 µg/m^3

Predicted 24-hour average $PM_{2.5}$ concentrations due to emissions

from the construction of the Hides Gas Conditioning Plant (see text) - µg/m^3

Figure 9

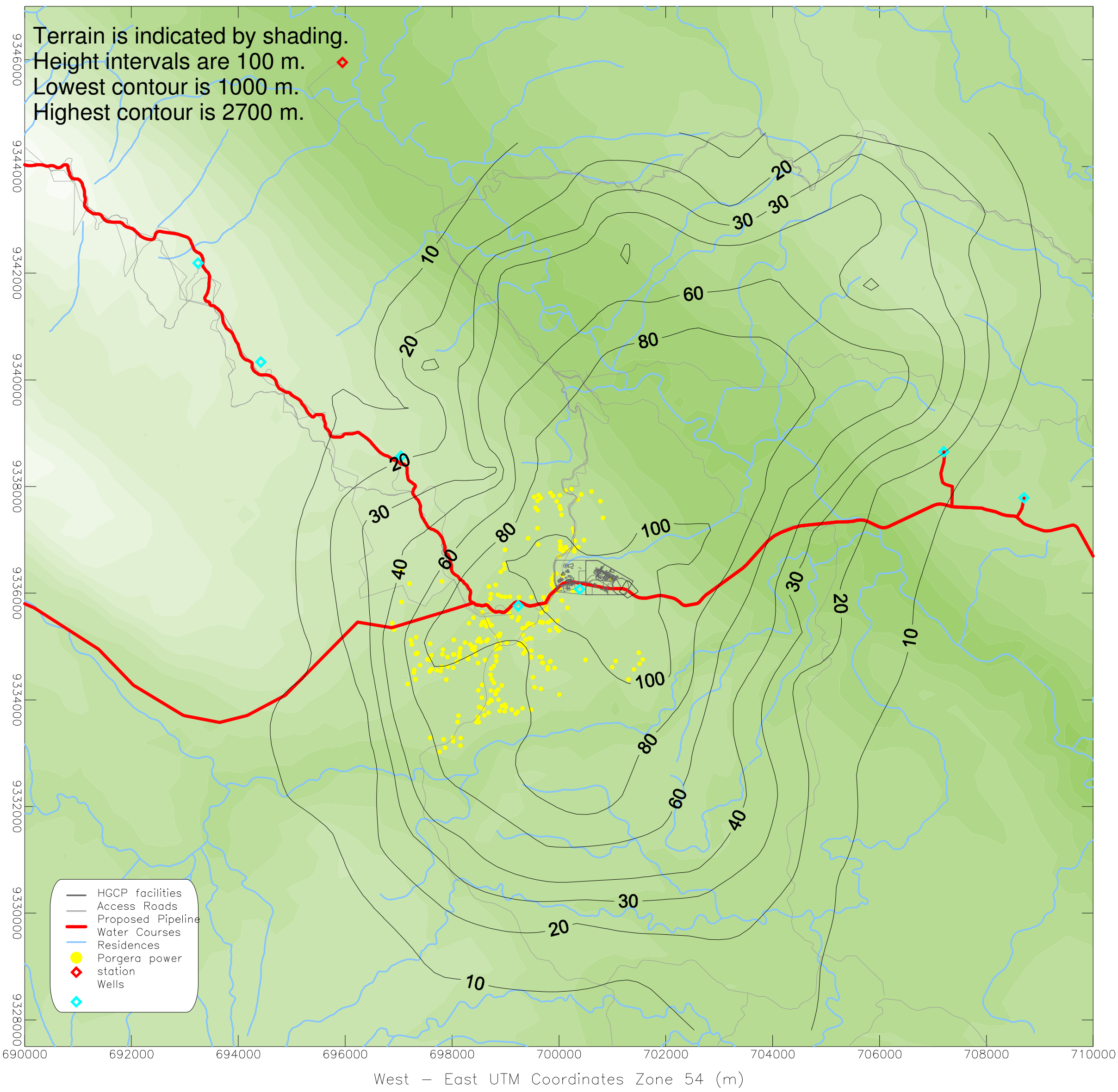


WHO (2005) (Interim target 1) annual guideline for $PM_{2.5}$ is 35 µg/m^3

Predicted annual average $PM_{2.5}$ concentrations due to emissions

from the construction of the Hides Gas Conditioning Plant (see text) - µg/m^3

Figure 10

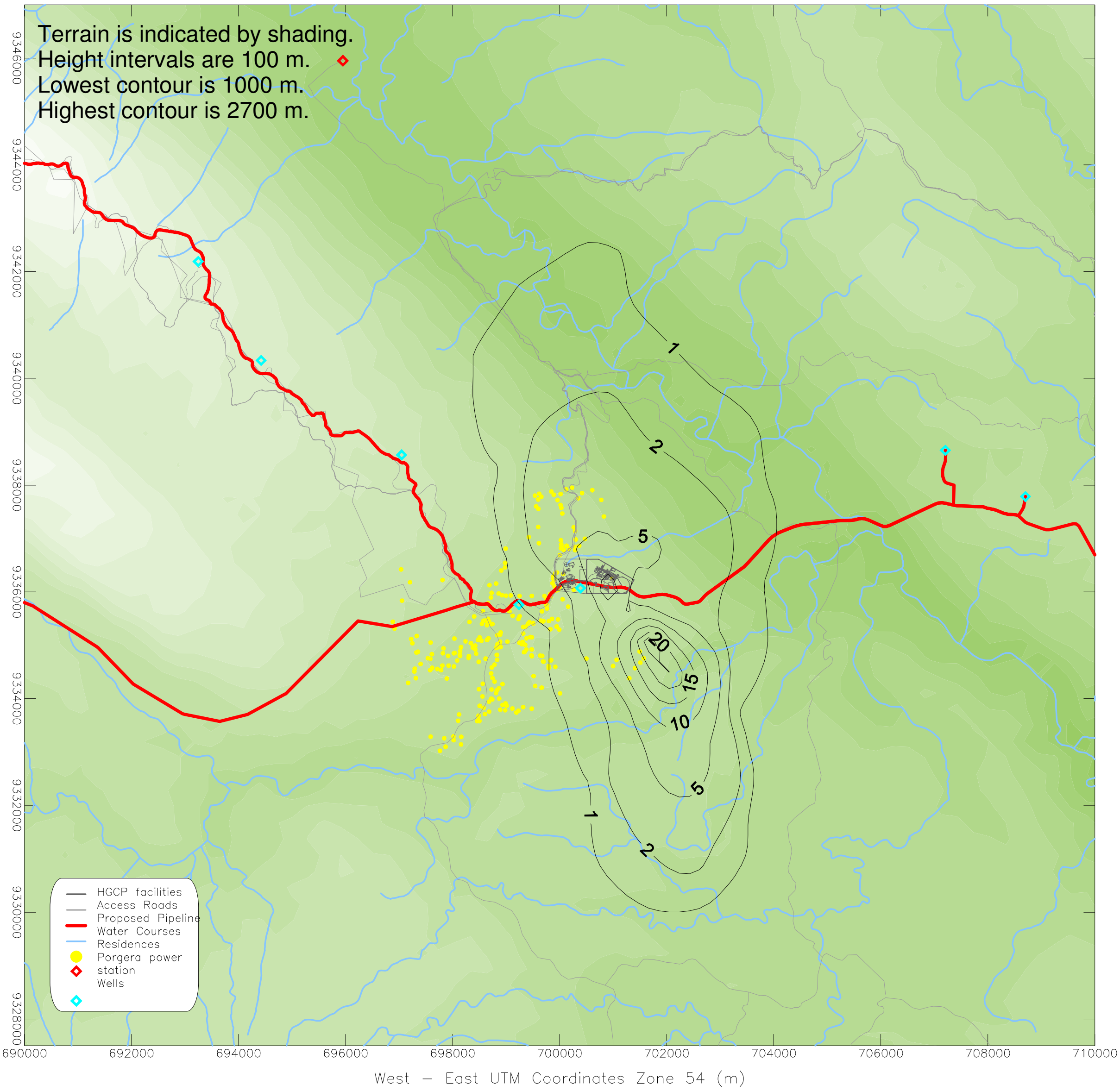


WHO guideline for 1-hour average NO_2 is 200 µg/m^3

Predicted maximum 1-hour concentrations of NO_2

due to emissions from the Hides Gas Conditiooning Plant (Stage 2) in isolation - µg/m^3

Figure 11

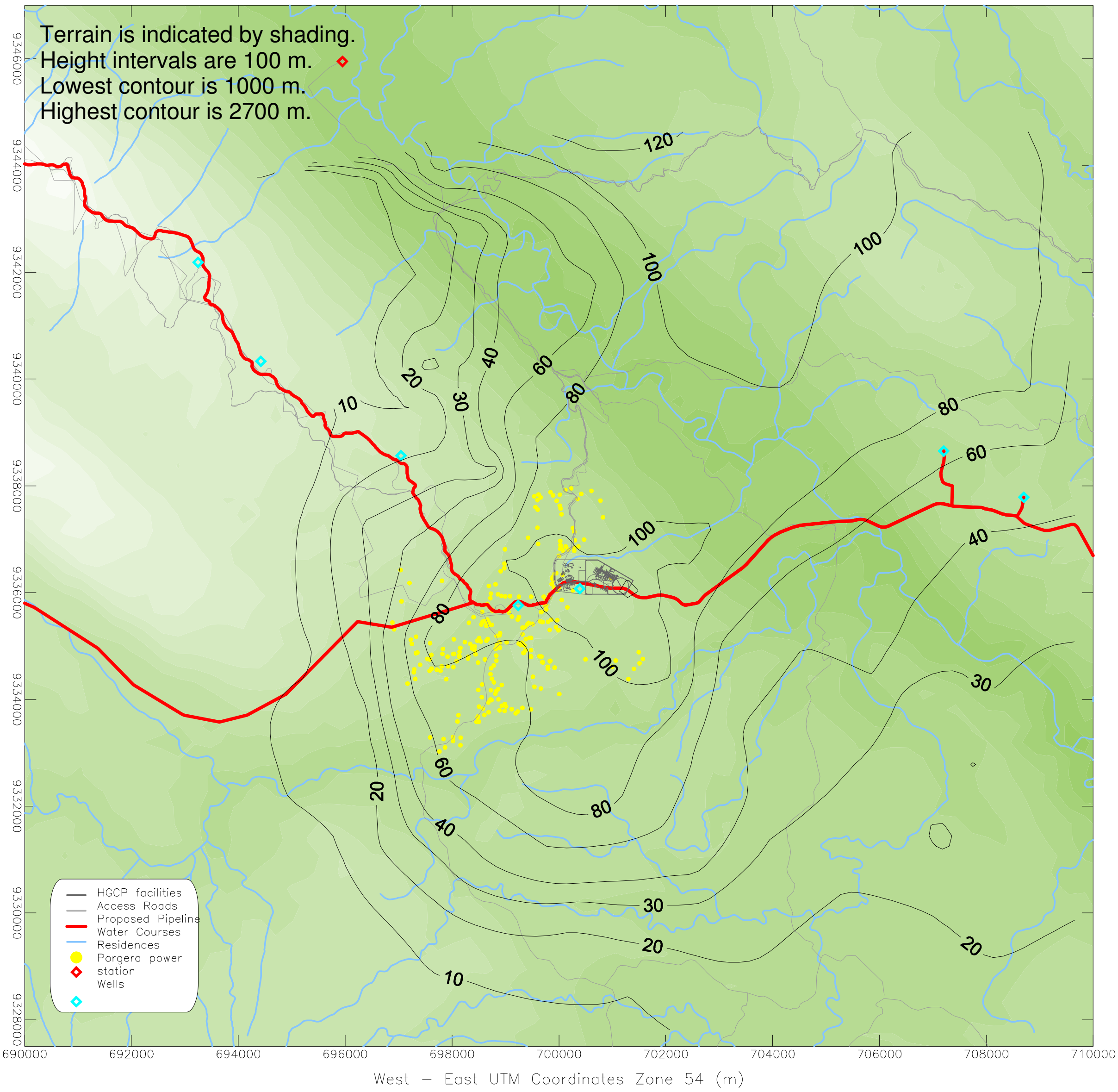


WHO (2005) guideline for annual average NO_2 is 40 µg/m^3

Predicted annual average concentrations of NO_2

due to emissions from the Hides Gas Conditioning Plant (Stage 2) in isolation - µg/m^3

Figure 12

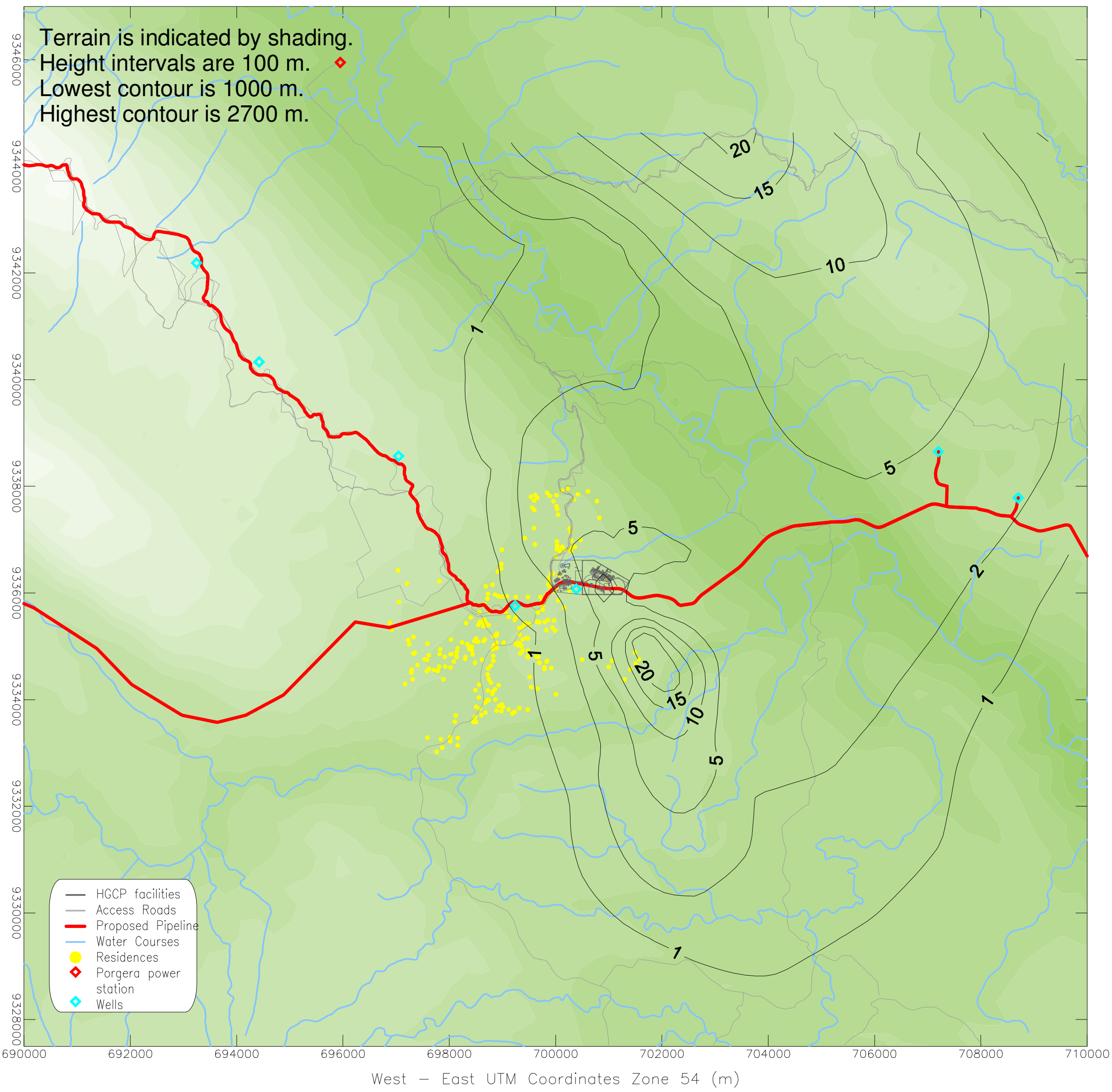


WHO (2005) guideline for 1-hour average NO_2 is 200 µg/m^3

Predicted maximum 1-hour average concentrations of NO_2

due to emissions from the Hides Gas Conditioning Plant (Stage 2) and Porgera Power Station - µg/m^3

Figure 13



WHO (2005) guideline for annual average NO_2 is 40 µg/m^3

Predicted annual average concentrations of NO_2

due to emissions from the Hides Gas Conditioning Plant (Stage 2) and Porgera Power Station - µg/m^3

Figure 14