

**AIR QUALITY ASSESSMENT:
PAPUA NEW GUINEA LIQUEFIED NATURAL GAS PROJECT (LNG FACILITIES)**

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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 downstream component of the Papua New Guinea Liquefied Natural Gas Project (PNG LNG 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 for over the 30 year life of the project.

A list of the proposed developments 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 spinline 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 spelines 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 spinline 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.

Two alternative designs for the LNG plant are being considered. These are referred to as Options 1 and 2. Option 1 is based on Aero-derivative (LM2500+) turbine drivers and Option 2 is based on industrial turbine drivers.

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, this report provides the following:

- A brief description of the project focussing on those aspects important from an air quality perspective.
- A review of the existing air quality in the area likely to be affected by emissions from the LNG plant.
- 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.
- An assessment of the air quality impacts likely to arise because of emissions from the LNG plant covering both Option 1 and Option 2.

- An assessment of the air quality impacts likely to arise because of construction work.
- An assessment of air quality impacts likely to arise because of project related traffic during construction and operation.
- An assessment of air quality impacts likely to arise because of emissions from shipping required to transport the LNG.

Project activities will be confined to the area indicated in Figure 2. Emissions from shipping will of course be over the entire route taken by shipping to international customers, but for the purposes of assessing the effects of emissions from shipping the focus has been confined to activities at the port (see Figure 2). This will capture the worst-case impacts for land-based and sea-based receptors (e.g. fishing boat etc).

The air quality impacts for the upstream components of this project have been assessed in a separate report (Holmes Air Sciences, 2008). This report and the upstream report have been written as standalone documents and as such cover similar background material.

2 DESCRIPTION OF THE PROJECT AND LOCAL SETTING

The project involves the construction and operation of an LNG production facility and associated port, roads and other infrastructure.

Figure 3 shows the location of the LNG Plant at Caution Bay State Portion 152 approximately 30 km northwest of Port Moresby.

The land on which the project would be constructed is gently undulating and largely cleared of trees. It has been used for grazing in the past and current land management practices result in it being periodically deliberately burnt. There are no significant air pollution emission sources in the area although the villages of Lae Lae, Papa and Boera (see Figure 2) and the roads that service them would contribute minor emissions of particles, NO_x, SO₂ and hydrocarbons. Natural sources of particulate matter such as sea salt and smoke from local and remote fires would also be present from time to time.

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 reflect 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 $\mu\text{g}/\text{m}^3$
2. 24-hour average 20 $\mu\text{g}/\text{m}^3$.

(Dispersion models generally provide estimates of pollutant concentrations averaged over periods of one hour or greater. Concentrations averaged over shorter intervals (e.g. 10-minute periods) can be estimated using the power law relationship suggested by Turner (1994). This 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 10-minutes, $(t_2 / t_1)^{0.2}$ is equal to 1.43. This means that a predicted sulphur dioxide 1-hour average concentration of 350 $\mu\text{g}/\text{m}^3$ is equivalent to a predicted 10-minute average of 500 $\mu\text{g}/\text{m}^3$. ($500/350 = 1.43$). Because the model used in this assessment provides estimates of 1-hour average concentrations rather than 10-minute averages the assessment criteria used has been the 1-hour average of 350 $\mu\text{g}/\text{m}^3$. From the above discussion this can be seen to be equivalent to a criterion of 500 $\mu\text{g}/\text{m}^3$ averaged over 10-minutes.)

The new 24-hour guideline of 20 $\mu\text{g}/\text{m}^3$ is significantly lower than the 125 $\mu\text{g}/\text{m}^3$ value suggested previously by the WHO (2000) and the 2005 document notes that the 24-hour average guideline of 20 $\mu\text{g}/\text{m}^3$ 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 $\mu\text{g}/\text{m}^3$
2. Interim target 2 (24-hour average), 50 $\mu\text{g}/\text{m}^3$.

WHO has withdrawn the annual average guideline of 40 to 60 $\mu\text{g}/\text{m}^3$ on the basis that compliance with a 24-hour average of 20 $\mu\text{g}/\text{m}^3$ would automatically ensure compliance with the annual guideline of 40 to 60 $\mu\text{g}/\text{m}^3$.

The ¹Interim 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.

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 low² and there is no prospect of the sulphur dioxide assessment criteria being exceeded by emissions from

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

the project. For this reason no modelling of sulphur dioxide emissions is undertaken. The same applies to the LNG Facilities, except that emissions from ships will contain higher concentrations of sulphur dioxide and these need to be assessed. The effects of sulphur dioxide emissions from shipping have been assessed via modelling in the LNG Facilities assessment and the Interim targets for sulphur dioxide have been used in assessing the effects of emissions from shipping.

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 $\mu\text{g}/\text{m}^3$
2. 30-minute average – 60,000 $\mu\text{g}/\text{m}^3$
3. 1-hour average – 30,000 $\mu\text{g}/\text{m}^3$
4. 8-hour average – 10,000 $\mu\text{g}/\text{m}^3$.

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.

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 $\mu\text{g}/\text{m}^3$ (WHO, 1987)
2. 24-hour average – 150 $\mu\text{g}/\text{m}^3$ (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 $\mu\text{g}/\text{m}^3$ and introduced a long-term guideline value of 40 $\mu\text{g}/\text{m}^3$. 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 $\mu\text{g}/\text{m}^3$ (WHO (2000) and WHO (2005))
2. Annual average – 40 $\mu\text{g}/\text{m}^3$ (WHO (2000) and 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.

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 $\mu\text{g}/\text{m}^3$; >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 $\mu\text{g}/\text{m}^3$ (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 $\mu\text{g}/\text{m}^3$ and a meta-analysis suggesting changes in airway responsiveness below 365 $\mu\text{g}/\text{m}^3$. (The significance of the response at 190 $\mu\text{g}/\text{m}^3$ (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 $\mu\text{g}/\text{m}^3$ is proposed. At double this recommended guideline (400 $\mu\text{g}/\text{m}^3$) 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 $\mu\text{g}/\text{m}^3$, 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 $\mu\text{g}/\text{m}^3$ (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 $\mu\text{g}/\text{m}^3$
2. 1-year – 4.5 $\mu\text{g}/\text{m}^3$.

Toluene³

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

Ethylbenzene

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

Xylenes (all except p-Xylene)

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

p-Xylene

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

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 guidelines now refer to concentrations of PM_{10} and $\text{PM}_{2.5}$ 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 $\text{PM}_{2.5}$.

PM_{10} (WHO, 2005)

1. Interim target 1, 24-hour average – 150 $\mu\text{g}/\text{m}^3$
2. Interim target 2, 24-hour average – 100 $\mu\text{g}/\text{m}^3$
3. Interim target 3, 24-hour average – 75 $\mu\text{g}/\text{m}^3$
4. Guideline, 24-hour average – 50 $\mu\text{g}/\text{m}^3$
5. Interim target 1, annual average – 70 $\mu\text{g}/\text{m}^3$
6. Interim target 2, annual average – 50 $\mu\text{g}/\text{m}^3$
7. Interim target 3, annual average – 30 $\mu\text{g}/\text{m}^3$
8. Guideline, annual average – 20 $\mu\text{g}/\text{m}^3$

$\text{PM}_{2.5}$ (WHO, 2005)

1. Interim target 1, 24-hour average – 75 $\mu\text{g}/\text{m}^3$
2. Interim target 2, 24-hour average – 50 $\mu\text{g}/\text{m}^3$
3. Interim target 3, 24-hour average – 37.5 $\mu\text{g}/\text{m}^3$
4. Guideline, 24-hour average – 25 $\mu\text{g}/\text{m}^3$

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 health impacts.

5. Interim target 1, annual average – 35 $\mu\text{g}/\text{m}^3$
6. Interim target 2, annual average – 25 $\mu\text{g}/\text{m}^3$
7. Interim target 3, annual average – 15 $\mu\text{g}/\text{m}^3$
8. Guideline, annual average – 10 $\mu\text{g}/\text{m}^3$

The WHO guideline document (WHO, 2005) discusses significance of these targets and guidelines⁴. 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 ($\text{PM}_{2.5}$) 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 $\text{PM}_{2.5}$ as an indicator and that the PM_{10} guidelines have been derived from by assuming that the ratio of $\text{PM}_{2.5}:\text{PM}_{10}$ concentrations is 50:100. This ratio has been selected because 0.5 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. The exception to this is emissions of particulate matter from shipping which easily comply with the most stringent criteria for PM_{10} and $\text{PM}_{2.5}$ (see later).

Total Suspended Particulate Matter (TSP)

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

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

Table 1. Ambient Air Quality Assessment Criteria (units are $\mu\text{g}/\text{m}^3$ 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)	500 125 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)		(not yet developed)	
Benzene - 1-hour - 1-year	170 ^c (0.022 ppm) 4.5 ^c (0.862 ppb)		170 4.5
Toluene - 1-hour - 1-year	640 ^c (0.500 ppm) 1,200 ^c (0.050 ppm)		640 1,200
Ethylbenzene - 1-hour - 1-year	2,000 ^c (0.423 ppm) 200 ^c (0.0423 ppm)		2,000 200
Xylene (o or m) - 1-hour - 1-year	3,700 ^c (0.901 ppm) 370 (0.091 ppm)		3,700 370
p-Xylene - 1-hour - 1-year	2,080 ^c (0.506 ppm) 208 (0.051 ppm)		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		
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

State Portion 152 is approximately 20 km northwest of Port Moresby and 15 km north-northwest of the InterOil Refinery at Napa Napa. These are the only significant sources of anthropogenic pollutants that could affect the area.

Appendix C of the Environmental Plan for the InterOil Refinery (**Kinhill Kramer, 1997**) provides information on the effect of emissions from the refinery. The predictions do extend out to the State Portion 152 area but interpolation of the available data indicates that the 99.9 percentile 1-hour

average SO₂ concentrations are unlikely to exceed 2 ppb (5.7 µg/m³) and annual average concentrations are unlikely to exceed 0.5 ppb (1.4 µg/m³) in the area of State Portion 152. Similarly for NO₂ the model predictions indicate that the 99.9 percentile of 1-hour average concentrations are expected to be less than 2 ppb (4 µg/m³) and annual average concentrations are expected to be well below 1 ppb (2 µg/m³) at State Portion 152.

Thus given this distance from Port Moresby and from the InterOil Refinery it is unlikely that any significant concentrations of industrial pollutants exist in the State Portion 152 area. To test this assumption a screening-type monitoring program was undertaken using passive monitors manufactured by Radiello and supplied and analysed by Leeder Consulting. The passive monitors comprise adsorbent and chemically treated substrates on cartridges that when exposed to ambient air containing specific pollutants either adsorb the pollutants (in the case of hydrocarbons) or chemically react with the material in the substrate. After exposure the cartridges are returned to the laboratory for analysis. The analysis provides information on the average concentration of pollutant at the site over the period that the cartridge was exposed.

Cartridges to monitor a suite of 32 hydrocarbons (including benzene, toluene, ethyl benzene and xylene (the BTEX compounds)), sulphur dioxide and nitrogen dioxide were exposed at three sites over a period of approximately 120 hours from 30 April to 5 May 2008. The three sites were:

1. Bible School (Outside chapel at UTM 55L 0503096 E and 8970520 N referred to as Site A).
2. Martha Cava (Residence at UTM 55L 0500815 E and 8970386 N referred to as Site B).
3. Muraka K Asi (Residence at UTM 55L 0502280 E and 8962702 N referred to as Site C).

The locations of the points are shown on Figure 3. Plate 1 shows the monitoring equipment in situ at Site A.



Plate 1. Showing Radiello passive monitor at Site A mounted near top of white post in centre of picture

Each site was equipped with two samplers of each type and one trip blank of each type was used to ensure that any incidental exposures to the pollutants that may have occurred in transit could be accounted for. The results are shown in **Table 2**.

All the monitored compounds were present at extremely low concentrations compared with the relevant assessment criteria and in most cases were below the detection limit of the method, which is shown in the table. The only pollutant present at a measureable concentration was SO₂ which was measured at concentrations of up to 3.4 µg/m³. This can be compared with the WHO criteria of:

1. 10-minute average 500 µg/m³ (WHO, 2005) (equivalent to a 1-hour average of 350 µg/m³ – see Section 3.1.1)
2. 24-hour average – 125 µg/m³ Interim target 1, 50 µg/m³ Interim target 2 and 20 µg/m³ final guideline (WHO, 2005).

Table 2. Monitored concentrations (120 hour averages) in area surrounding State Portion 152 - $\mu\text{g}/\text{m}^3$.

Sample ID Site Sample number→	O890J Site A Sample 1	O892J Site A Sample 2	O893J Site B Sample 1	O897J Site B Sample 2	O901J Site C Sample 1	O903J Site C Sample 2
Substance ↓						
Benzene	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17
Bromochloromethane	<0.19	<0.19	<0.2	<0.2	<0.19	<0.19
Butanol	<0.18	<0.18	<0.19	<0.19	<0.18	<0.18
2-butoxyethanol	<0.24	<0.24	<0.25	<0.25	<0.24	<0.24
Butyl acetate	<0.23	<0.23	<0.23	<0.23	<0.23	<0.23
Cyclohexane	<0.25	<0.25	<0.26	<0.26	<0.25	<0.25
Cyclohexanone	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
n-decane	<0.32	<0.32	<0.32	<0.32	<0.32	<0.32
1,2-Dichloropropane	<0.21	<0.21	<0.21	<0.21	<0.21	<0.21
Ethyl acetate	<0.17	<0.17	<0.18	<0.18	<0.17	<0.17
Ethyl benzene	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ethyl-ter-butyl ether	<0.22	<0.22	<0.23	<0.23	<0.22	<0.22
n-Heptane	<0.24	<0.24	<0.24	<0.24	<0.23	<0.23
n-Hexane	<0.21	<0.21	<0.21	<0.21	<0.21	<0.21
Isobutanol	<0.18	<0.18	<0.18	<0.18	<0.18	<0.18
Isooctane	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Isopropylbenzene	<0.24	<0.24	<0.24	<0.24	<0.23	<0.23
1-Methoxy-2-propanol	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
1-Methoxy-2-propyl acetate	<0.23	<0.23	<0.23	<0.23	<0.23	<0.23
Methyl methacrylate	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Methylethylketone	<0.17	<0.17	<0.18	<0.18	<0.17	<0.17
Methylisobutylketone	<0.2	<0.2	<0.21	<0.21	<0.2	<0.2
2-Methylpentane	<0.19	<0.19	<0.2	<0.2	<0.19	<0.19
3-Methylpentane	<0.19	<0.19	<0.2	<0.2	<0.19	<0.19
Methyl-ter-butyl ether	<0.21	<0.21	<0.21	<0.21	<0.21	<0.21
N-Octane	<0.26	<0.26	<0.26	<0.26	<0.26	<0.26
Styrene	<0.22	<0.22	<0.23	<0.23	<0.22	<0.22
Tetrachloroethylene	<0.23	<0.23	<0.24	<0.24	<0.23	<0.23
Toluene	<0.18	<0.18	<0.19	<0.19	<0.18	<0.18
1,1,1-Trichloroethane	<0.22	<0.22	<0.22	<0.22	<0.22	<0.22
Trichloroethylene	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Xylenes	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Sulphur Dioxide	<2.1	3.4	<2.1	3.1	2.6	<2.1
Nitrogen dioxide	<2.1	<2.1	<2.1	<2.1	<2.1	<2.1

The LNG plant will be a source of particulate matter (TSP and PM_{10}) during construction and there will also be emissions of PM_{10} from shipping. During the operational phase of the plant emissions of particulate matter would be expected to be negligible. This is because the principal fuel to be used will be natural gas which burns cleanly. However to consider the effects of particle emissions during construction it is useful to estimate the likely concentrations of TSP and PM_{10} . Based on a site inspection and a review of existing land use in the area it is concluded that PM_{10} concentrations are unlikely to exceed $20 \mu\text{g}/\text{m}^3$ (annual average). TSP concentrations are unlikely to exceed $40 \mu\text{g}/\text{m}^3$. Short-term (24-hour) concentrations of PM_{10} may be elevated from time-to-time when smoke from fires affect the area. Concentrations of PM_{10} may exceed the assessment criteria under these conditions. This type of phenomenon is not uncommon and occurs regularly in Australia and

presumably in much of PNG whenever uncontrolled bushfires or controlled burns (used to manage vegetation loads) contribute smoke to the airshed.

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 class⁵ and mixing height⁶.

A meteorological station has been established at State Portion 152 however insufficient data have been collected at the time of writing to allow an air quality assessment to be undertaken using the data. Instead the required data have 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 Latitude -9.3917 degrees south and Longitude 147.0250 degrees east. Since the TAPM model is used to develop hourly information about meteorological conditions over a grid of points spaced at 1 km interval (covering an area 24 km (north-south) by 24 km (east-west) this location centre of the grid is not critical. There is no particular reason for selecting 2006 data for modelling except that it was the most up-to-date complete year of TAPM data available at the time that the air quality studies were commenced.

Figure 4 presents annual and seasonal⁷ windroses prepared from the data collected so far by the project meteorological station (located near Site C see Figure 3). Figure 5 shows annual and seasonal windroses for the 2006 TAPM simulations for the location referred to above (see also Figure 3). However it is relevant to note that the dispersion modelling undertaken for the assessment does not make use of the data from a single location but uses a three dimensional wind field that recognises that dispersion conditions vary with space and time over the modelling domain and over the year for which the model simulations have been undertaken.

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.

6 MODELLING METHODOLOGY

The US EPA approved dispersion model CALMET/CALPUFF (version 5) (Scire et al., 2000A and Scire et al., 2000B) has been used to assess the effects of emissions from the LNG plant and from associated activities including shipping, construction and road transport.

6.1 Preparation of meteorological data files

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 1000 m apart in the horizontal and nine levels in the vertical⁸ and covering an area 40 km by 40 km with the southwest corner of the grid at Universal Transverse Mercator (UTM) coordinate 482700 mE and 8941800 mN (Zone 54S). The proposed LNG Plant is located at the approximate centre of this grid.

The wind information was developed by CALMET using output from TAPM (see Section 5). 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:

- 502700 mE and 8961800 mN
- 493700 mE and 8967800 mN
- 499700 mE and 8951800 mN
- 509700 mE and 8970800 mN
- 512700 mE and 8970800 mN

These points are intended to provide the model with information on dispersion conditions in and over the area into which the emissions will be dispersed.

In addition, TAPM was used to calculate wind and temperature profiles up to 2500 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.

6.2 Dispersion

Dispersion was simulated using the CALPUFF model. 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.

6.3 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 NO₂ and the remainder will be in the form of the less harmful NO. Over time NO is oxidised to NO₂ and later to nitrates. The rate of oxidation depends on the concentration of oxidants in the atmosphere, primarily on the concentration of ozone (O₃).

⁸ 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 assessment is undertaken by comparing the concentrations of NO₂, rather than NO_x with the assessment criteria.

In the lower atmosphere, O₃ 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 O₃ 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 O₃ 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 NO₂ concentration to be made in a NO_x plume. The calculation requires knowledge of the background O₃ 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 O₃ concentrations will be in the range 20 to 40 ppb (43 to 86 µg/m³), which is the range quoted by Seinfeld and Pandis (1998) for remote areas.

The OLM method can be summarised by the following equation:

$$[\text{NO}_2]_{\text{total}} = \{0.1 \times [\text{NO}_x]_{\text{predicted}}\} + \text{minimum of } \{0.9 \times [\text{NO}_x]_{\text{predicted}} \text{ or } (46/48) \times [\text{O}_3]_{\text{background}}\} + [\text{NO}_2]_{\text{background}}$$

Where,

$[\text{NO}_2]_{\text{total}}$ = the predicted concentration of NO₂, via OLM, in µg/m³,

$[\text{NO}_2]_{\text{predicted}}$ = the predicted concentration of NO₂ in µg/m³ from the dispersion model in µg/m³,

$[\text{O}_3]_{\text{background}}$ = the background concentration of O₃ in µg/m³,

46/48 = the molecular weight of NO₂ divided by the molecular weight of O₃, and

$[\text{NO}_2]_{\text{background}}$ = the background concentration of NO₂ in µg/m³.

If the $[\text{O}_3]_{\text{background}}$ is taken to be 86 µg/m³ (the upper end of the range suggested by Seinfeld and Pandis) and $[\text{NO}_2]_{\text{background}}$ is taken to be zero (since there are no significant sources of NO₂ present in the area apart from those included in the model), then the value of NO₂ 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 µg/m³.

7 PROJECT EMISSIONS

This section identifies emission sources associated with the project and provides where possible, quantitative estimates of emissions for significant sources. 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).

The project involves a number of distinct activities that will give rise to air emissions. These are discussed briefly here. More detailed information is provided under separate subheadings later in this section.

Initially there will be emissions from earthworks associated with the preparation of the ground for the construction of the temporary and permanent accommodation camps and later with the preparation of the site for the LNG plant production trains and associated tanks, flares, roads etc.

The air quality effects of the earthworks will occur over many months but will nevertheless be temporary. Air quality effects of construction will depend on seasonal conditions at the time the work is undertaken.

During the production phase emissions will occur from the gas-fired plant and will largely involve emissions of NO_x. These emissions will occur over the long-term corresponding with the life of the proposal. At the time of writing two options are under consideration (1) Aero Frame Technology and (2) Industrial Frame. Both of these options are assessed.

There will also be emissions of SO₂, NO_x and PM₁₀ from shipping and tugs servicing the plant.

Minor emissions will arise from traffic using the roads to access the site. Heavy equipment will be brought to the site by barge or ship and so these impacts will be confined mostly to emissions from light vehicles transporting supplies and people to and from the site and villages beyond.

7.1 Construction

7.1.1 LNG Plant, Camps, Access roads etc

Emissions from constructing the LNG facility and the support facilities (e.g. the temporary camp to house the construction workforce, the permanent housing for the plant workforce, the pipeline and jetty) will include dust from earthworks and emissions of NO_x, CO, minor quantities of SO₂ and VOCs from internal combustion engines (mostly diesel-powered earthmoving equipment).

The total area within the perimeter fence of the LNG plant is 703 ha. The areas associated with the more significant components of the facility from the point of view of earthworks are as follows:

- Flare Area, 2.25 ha
- Process Unit (2 trains), 40.08 ha
- Support Buildings, 16.77 ha
- Temporary Construction Camp, 73.81 ha
- Permanent Living and Support Facilities, 20.00 ha
- Tankage, 262.98 ha
- Helipad, 1.00 ha
- LNG TK1, 30.85 ha
- Spoil storage areas, 60 ha approximately
- Future Process Unit (2 trains) 40.08 ha (not considered in this assessment).

The total area involved is approximately 448 ha. It is unrealistic to assume that all 448 ha are worked on simultaneously and to adopt a more realistic, but still conservative approach to the assessment it will be assumed that half of the 448 ha of land is exposed and is being worked on under the busiest phase in the construction. This has been done to account for the fact that certain construction activities would be completed or be left in a condition where emissions are negligible before other works are commenced. For example the temporary construction camp will be completed and stabilised before the majority of the works are commenced and there are likely to be other activities that will be completed progressively as the construction proceeds. Similarly the spoil areas could be revegetated progressively to avoid the creation of large areas susceptible to generating windblown dust.

The overall construction is expected to take place over approximately four years. The precise details as to how the works would be conducted have not yet been finalised and for this reason a detailed emissions inventory for earthworks cannot be developed, however emissions can be estimated using the single value emission factor published in AP42 by the US EPA (1985 and updates) (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 for work 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).

Based on a construction area of approximately 448 ha, the estimated emission rate of TSP during construction is 1,205 t/month [448 ha x 2.69 t/ha], or 464.9 g/s [1,205 t/month x 10^6 g/t / (30 days/month x 24 h/day x 3600 s/h)]. In the modelling (see Section 8.2) the PM_{10} emissions have been assumed to be the half the TSP emission rates. Data in AP42 and elsewhere suggests that this is a reasonable factor to apply for dust emissions from earthmoving operations. Since rainfall in the area is somewhat higher than the areas for which the AP42 factor, applies the estimated emissions are likely to be conservative.

Works to upgrade access roads will also be required. The effects of emissions associated with these short-term activities have not been assessed specifically by modelling but standard controls as applied in PNG and internationally will be applied to control dust with particular care being applied to controls when works are taking place close to houses and places where dust emissions could cause nuisance effects.

7.1.2 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 reduce the 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 for the sulphur levels will comply with local regulations for on-road vehicles.
- A dust management plan will be developed to control and manage dust emissions from construction work, measures will include:
 - imposing speed limits on-site to be controlled via posted speed limit signs
 - vehicles will be kept to marked trafficable areas which would be maintained in a damp and compacted condition to enhance safety and minimise dust emissions.
 - water carts to be used to keep trafficked surfaces damp when conditions are dry.
 - Exposed areas susceptible to generating wind erosion dust will be kept to the minimum required for efficient construction and those areas that are observed to generate dust will be treated either with hydro mulch or other dust suppressant methods.

7.2 LNG Plant Operations

As noted previously, two options have been assessed, both involve two production trains. The emissions from the two options are discussed below.

7.2.1 LNG Plant – Option 1

Option 1 is based on Aero-derivative (LM2500+) turbine drivers. This will involve the following equipment.

- Four (LM2500+) power generator turbines, four of which would be operated normally at 75% load. In the event of a failure the plant would continue to operate on three turbines at full load. The assessment has been based on normal operations with all four turbines operating on 75% load.
- Four (two per train) (LM2055+) propane compressor turbines.
- Six (three per train) (LM2500+) compressor turbines.
- Two (one per train) acid gas incinerators
- One flare.

These items will be sources of NO_x and hydrocarbons (HC). The emissions information required for modelling the dispersion of NO_x and hydrocarbons from these items is summarised in **Table 3**.

Table 3. Emissions from Option 1 – Aero-derivative (LM2500+) turbine drivers 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 (°K)	Emission rate as NO ₂ / HC (g/s)
1	P1PGT ¹	501873	8967552	30.0	15.1	3.0	18.5	823.0	2.08 / 0.43
2	P2PGT	502955	8967614	30.0	17.5	3.0	18.5	823.0	2.08 / 0.43
3	P3PGT	502081	8967708	30.0	22.7	3.0	18.5	823.0	2.08 / 0.43
4	P4PGT	502168	8967770	30.0	26.8	3.0	18.5	823.0	2.08 / 0.43
5	P5PCT ²	502127	8967281	40.0	19.7	3.0	17.3	573.0	2.88 / 0.59
6	P6PCT	502191	8967336	40.0	21.2	3.0	17.3	573.0	2.88 / 0.59
7	P7PCT	501982	8967428	40.0	16.9	3.0	17.3	573.0	2.88 / 0.59
8	P8PCT	502036	8967472	40.0	18.5	3.0	17.3	573.0	2.88 / 0.59
9	P9MRCT ³	501828	8967656	40.0	20.0	3.0	17.3	573.0	2.88 / 0.59
11 ⁴	P9MRCT	502090	8967515	40.0	15.3	3.0	17.3	573.0	2.88 / 0.59
12	P9MRCT	502090	8967515	40.0	17.8	3.0	17.3	573.0	2.88 / 0.59
13	P9MRCT	502090	8967515	40.0	13.6	3.0	17.3	573.0	2.88 / 0.59
14	P9MRCT	502090	8967515	40.0	15.3	3.0	17.3	573.0	2.88 / 0.59
15	P9MRCT	502090	8967515	40.0	16.9	3.0	17.3	573.0	2.88 / 0.59
10	P10AGI ⁵	502133	8967627	30.0	22.3	1.0	18.3	1088	0.5 / 0.05
16	P16AGI	501872	8967994	30.0	18.6	1.0	18.3	1088	0.5 / 0.05
17	P17Flare	501863	8968666	30.0	20.0	1.0	20.0	789	1.0 / neg

Notes:

¹ Power Generator Turbine

² Propane Compressor Turbine

³ MR Compressor Turbine

⁴ Not in sequence

⁵ Acid Gas Incinerator.

Note the plant to be used in the project (see **Table 3**) employs NO_x control technology and uses stack heights that are appropriately designed for the emissions. The modelling reported in Section 8 shows that the relevant air quality assessment criteria are predicted to be met for all categories of emission from the plant.

7.2.2 LNG Plant – Option 2

Option 2 is based on industrial turbine drivers and would involve the following equipment.

- Four (Frame 5) power generator turbines, four of which would be operated normally at 75% load. In the event of a failure the plant would continue to operate on three turbines at full load. The assessment has been based on normal operations with all four turbines operating on 75% load.
- Two (one per train) (Frame 7) propane compressor turbines running at partial load.
- Two (one per train) (Frame 7) compressor turbines.
- Two (one per train) acid gas incinerators
- One flare.

As for Option 1 these items will be sources of NO_x and hydrocarbons. The emissions information required for modelling the dispersion of NO_x and hydrocarbons from these items is summarised in **Table 3**. The emission estimates have been provided by Exxon and take into account the load factor for each item of plant assuming normal operating conditions.

Table 4. Emissions from Option 2 – Industrial turbine drivers 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 (°K)	Emission rate as NO ₂ / HC (g/s)
1	P1PGT ¹	501873	8967552	30.0	15.1	3.2	20.5	823.0	2.59 / 0.28
2	P2PGT	502955	8967614	30.0	17.5	3.2	20.5	823.0	2.59 / 0.28
3	P3PGT	502081	8967708	30.0	22.7	3.2	20.5	823.0	2.59 / 0.28
4	P4PGT	502168	8967770	30.0	26.8	3.2	20.5	823.0	2.59 / 0.28
5	P5PCT ²	502127	8967281	40.0	19.7	4.5	22.2	573.0	7.96 / 0.87
6	P6PCT	502191	8967336	40.0	21.2	4.5	22.2	573.0	7.96 / 0.87
9	P9MRCT ³	501982	8967428	40.0	16.9	4.5	29.7	573.0	10.66 / 1.16
11 ⁴	P9MRCT	502036	8967472	40.0	18.5	4.5	29.7	573.0	10.66 / 1.16
10	P10AGI ⁵	502133	8967627	30.0	22.3	1.0	18.3	1088	0.5 / 0.05
16	P16AGI	501872	8967994	30.0	18.6	1.0	18.3	1088	0.5 / 0.05
17	P17Flare	501863	8968666	30.0	20.0	1.0	20.0	789	1.0 / neg

Notes:

¹ Power Generator Turbine

² Propane Compressor Turbine

³ MR Compressor Turbine

⁴ Not in sequence

⁵ Acid Gas Incinerator.

As for Option 1, the plant to be used in the project (see **Table 4**) employs NO_x control technology and uses stack heights that are appropriately designed for the emissions. The modelling reported in Section 8 shows that the relevant air quality assessment criteria are predicted to be met for all categories of emission from the plant.

7.3 Emissions from shipping

In contrast to the LNG plant which involves fixed emissions sources operating at approximately constant emission rates over extended periods of time, shipping will involve mobile sources with emissions that vary with time. This makes the assessment more complicated. However the

assessment can be simplified if a conservative emissions scenario can be used as the basis of the assessment.

LNG tankers will approach the wharf via the shipping channel and will be assisted by tugs. The basis of the assessment has been to assume that the tanker is moored at the wharf and is assisted by four tugs that are located in the immediate vicinity of the tanker and wharf. There will be approximately 68 port calls per year, or slightly over one per week. Each port call would take approximately 34 hours of which approximately 20 hours would be taken up by loading. This latter information has not been used in the modelling but is useful to note that shipping emissions would be present in the area for approximately 26% of the hours in the year.

The tanker and tugs are assumed to burn heavy fuel oil (HFO at 3% sulphur) and marine diesel oil (MDO at 2% sulphur) and will liberate SO_2 , NO_x and PM_{10} through a funnel. Emissions parameters including the emission rate, funnel diameter, funnel height, exit velocity and exit temperature have been provided by Exxon and are summarised in **Table 5**.

Tankers have been assumed to be equipped with:

- Two 2.64 MW fuel oil-powered generators
- Two 12.195 MW fuel oil-powered main engines
- One 8,000 kg/h auxiliary boiler.

Tugs have been assumed to be 80 ton BP tugs each equipped with:

- Two 2.320 MW main engines
- Two 250 kW generators.

Table 5. Emissions from shipping worst case scenario (HFO 3% sulphur, MDO 2% sulphur)¹

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 (°K)	Emission rate - g/s		
									SO ₂	NO ₂	PM ₁₀
1	SHIPDG ²	498716	8966639	32.0	0	0.6	29.0	658.0	33.361 25.280 ^a	31.000 23.470 ^a	2.194 1.650 ^a
2	SHIPME ³	498716	8966639	32.0	0	1.0	9.0	603.0	17.944 2.690 ^a	20.667 3.098 ^a	1.472 0.220 ^a
3	SHIPAB ⁴	498716	8966639	32.0	0	0.25	6.31	427.0	2.194 2.190 ^a	0.361 0.360 ^a	0.225 0.225 ^a
4	TUG1	498700	8966000	15.0	0	0.45	28.0	628.0	24.194	23.111	0.806
4	TUG1	498700	8966000	15.0	0	0.45	28.0	628.0	24.194	23.111	0.806
4	TUG1	498700	8966000	15.0	0	0.45	28.0	628.0	24.194	23.111	0.806
4	TUG1	498700	8966000	15.0	0	0.45	28.0	628.0	24.194	23.111	0.806

¹ Source: Data taken from "PNG Emissions Template Rev G 10 July 08.xls"² LNG tanker diesel generators³ LNG main engines⁴ LNG Tanker auxiliary boilers^aTime averaged emission rate (see text below)

In assessing impacts for maximum one hour concentrations the tugs and tanker have been assumed to be at the jetty for the entire year and the tugs have also been assumed to be in the vicinity of the jetty (within a few tens of metres) for the whole year. Emissions have been taken to be the maximum emission rates for tankers and tugs determined by Exxon for the entire year. This assumption has been made because the worst-case dispersion condition could occur at the same time as the maximum emissions. However for 24 hours and annual averages it is inappropriate to assume that emissions occur continuously at the maximum rate for all hours in the year. To deal with this situation Exxon had analysed the shipping operations and divided the procedure into various phases and have estimated the emissions appropriate to each phase. For modelling of 24-hour and annual averages sulphur dioxide concentrations, the time weighted average emissions over the 34 hour docking and loading procedure have been calculated. These have been used in the modelling. The CALPUFF dispersion model has then been run to provide predictions of the following:

- Maximum 1-hour average NO₂ concentrations
- Annual average NO₂ concentrations
- Maximum 1-hour average SO₂ concentrations
- Maximum 24-hour average SO₂ concentrations
- Annual average SO₂ concentrations⁹
- Maximum 24-hour average PM₁₀ concentrations
- Annual average PM₁₀ concentrations
- Maximum 1-hour average VOC concentrations.

7.4 Thermal emissions

The plant will be a direct source of thermal emissions the most visible of which will be associated with the flare but there will also be significant emissions from turbines used to drive compressors and generators. The heat from the flare will require a purpose designed exclusion zone to prevent workers from being exposed to excessive radiant heat. However the effects of these thermal emissions have extremely local effects and will be essentially unmeasurable at the closest residences. The quantity of gas to be flared could reach 90,596 kg/h (refer to email from Ram Narayan to Kewan Bond, 10 July 2008). Based on an energy content of 53.2 MJ/kg in the natural gas, the heat released could therefore reach 4.820×10^{12} J/h.

On average the earth's surface receives solar energy at the rate of approximately 300 W/m², or 1.080×10^6 J/h. This is the average over the whole day over the whole of the earth's surface. Thus, at maximum flow to the flare, the energy released per hour could reach the same value as the average energy received from the sun by 446 ha of land surface. If the figure is compared with the maximum energy flux to the earth's surface from the sun at mid-day in PNG, the area would be smaller by a factor of approximately three. Clearly the direct effect of heat from the flare even at maximum gas flow will only have very local effects on the heat load to the environment.

Note this calculation has no relationship to greenhouse gas effects, which are assessed elsewhere in the EA.

⁹ Note: WHO (2005) no longer refers to an annual average guideline for sulphur dioxide, however it is still useful to provide information on the annual average concentration when the Interim WHO guideline values are being used.

8 ASSESSMENT OF EFFECTS

8.1 Preamble

The impacts of activities that are likely to result in significant emissions have been assessed using dispersion modelling. For some activities such as emission of CO from turbines and generators where emissions are low no model results are presented. The fact that CO emissions will comply with the relevant assessment criteria can be determined by noting that the emissions of CO will for every emission on the plant, be much less than emissions of NO_x and the assessment criterion for 1-hour CO concentrations is 30,000 µg/m³ compared with the 1-hour average assessment criterion for NO₂ which is 200 µg/m³, i.e. the assessment criterion is 1500 higher for CO than for NO₂.

The modelling assessment has focussed on assessing the effects of:

- TSP and PM₁₀ emissions during construction
- Emissions of NO₂, SO₂ from fixed plant on shore for Option 1 and 2
- Emissions of NO₂, SO₂ and PM₁₀ from shipping
- Combined effects of NO₂ and SO₂ from shipping for Option 2 (the worst-case).

Note in some jurisdictions in Australia dust deposition has been included in the range of pollutants assessed. However this is not common in international assessments and in Australia it is almost universally true that compliance with the annual average PM₁₀ criterion will automatically ensure compliance with dust deposition criteria. For these reasons dust deposition has not been assessed.

8.2 Construction of LNG Plant, Camps, Access roads etc

Figure 6 and Figure 7 show respectively the predicted maximum 24-hour and annual average TSP concentrations due to emissions from construction work based on the assumptions about emissions discussed in Section 7.1.1. Figures 8 and 9 show the maximum 24-hour and annual average PM₁₀ concentrations respectively.

PM₁₀ is a subcomponent of TSP and typically PM₁₀ concentrations will be approximate 40 to 60% of the TSP concentration depending on the sources. When windblown dust or dust from construction or agriculture activities are the dominant sources, then the PM₁₀ concentration is likely to be closer to 40% of the TSP concentration. By contrast when combustion sources are dominant, the finer fraction will dominate and PM₁₀ concentrations are likely to be closer to 60% of the TSP concentration. The assessment undertaken here assumes that the PM₁₀ concentrations are 50% of the TSP concentrations. The WHO (2005) also sets assessment criteria for PM_{2.5}, which are set at 50% of the PM₁₀ concentration limits. Since the fraction of particles in dust from construction operations that are in the PM_{2.5} size range is small (PM_{2.5} concentrations in construction dust is less than 50% of the concentration of PM₁₀ – see SPCC (1986)), compliance with the WHO's PM₁₀ assessment criteria implies compliance with the PM_{2.5} criteria. For this reason no separate modelling has been undertaken for PM_{2.5} concentrations arising from construction.

The predictions cover worst-case meteorological conditions. The predicted concentrations need to be considered in the context of the prevailing background TSP and PM₁₀ concentrations which for 24-hour TSP and PM₁₀ concentrations will be highly variable and may from time to time exceed the WHO (1987) TSP guideline of 150 to 230 µg/m³ and the WHO (2005) Interim target 1 24-hour criteria of 150 µg/m³ for PM₁₀. This would be most likely when grass fires, employed as part of local land management/agricultural practices, contribute to smoke in the local airshed.

The modelling results in Figure 6 indicate that the worst-case 24-hour TSP concentration due to emissions from the construction work at the most affected residences (see Sites A and B on Figure 3)

is $130 \mu\text{g}/\text{m}^3$ compared with the WHO criterion of 150 to $230 \mu\text{g}/\text{m}^3$. This would allow background concentrations of 20 to $100 \mu\text{g}/\text{m}^3$ to prevail before the criterion was exceeded. Figure 7 indicates that the annual average TSP concentration due to emissions from the construction work at the most affected residence is $38 \mu\text{g}/\text{m}^3$ compared with the WHO (2005) Interim target 1 of 60 to $90 \mu\text{g}/\text{m}^3$. This would allow background concentrations of $22 \mu\text{g}/\text{m}^3$ to prevail before the target was exceeded. Because of the current land use in the area and the lack of sources that would liberate TSP, it is unlikely that annual average TSP concentration would be as high as $22 \mu\text{g}/\text{m}^3$ anywhere on or near the project area.

The modelling results in Figure 8 indicate that the worst-case 24-hour PM_{10} concentration due to emissions from the construction work at the most affected residence is $65 \mu\text{g}/\text{m}^3$ compared with the WHO (2005) Interim target 1 of $150 \mu\text{g}/\text{m}^3$. This would allow a background concentration of $85 \mu\text{g}/\text{m}^3$ to prevail before the criterion was exceeded. Figure 9 shows that the annual average PM_{10} concentration due to emissions from the construction work at the most affected residence is $19 \mu\text{g}/\text{m}^3$ compared with the WHO (2005) Interim target 1 of $70 \mu\text{g}/\text{m}^3$. This would allow background concentrations of $51 \mu\text{g}/\text{m}^3$ to prevail before the target would be exceeded. Based on a site inspection and review of existing land use it is unlikely that annual average PM_{10} concentrations would be as high as $51 \mu\text{g}/\text{m}^3$ anywhere on or near the project area.

Standard mitigation measures as discussed in Section 7.1.2 would be applied to reduce dust emissions.

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 qualitatively considered in conjunction with emissions from other sources. The reason that no detailed analysis is provided taking account of emissions from other sources of pollution is that the other sources are at sufficient distances from State Portion 152 that their effects in the area are negligible. This is discussed in Section 4 and is supported by the results of the on-site monitoring work also discussed in Section 4.

8.3.1 LNG Plant Option 1

Figures 10 to 13 show the predicted effects of emissions of NO_2 and HC from operations of Option 1 (Aero derivative option) of the LNG Plant using the emissions data in Section 7.2.1. The figures show isopleths for the following:

- Maximum 1-hour average NO_2 concentrations
- Annual average NO_2 concentrations
- Maximum 1-hour average benzene concentrations
- Annual average concentrations.

The LNG Plant is not a significant source of particulate matter or of SO_2 and so no modelling of these are presented, although they are considered later when emissions from shipping are assessed.

Hydrocarbon emissions (also referred to as VOCs) have been model without regard for the particular hydrocarbon species involved. In the assessment it has been assumed that all emissions are in the form of benzene. Since benzene has the most stringent assessment criteria, compliance with the benzene criteria automatically implies compliance with the other VOC criteria.

Each figure shows the relevant assessment criterion. It can be seen that the emissions are not predicted to exceed any of the assessment criteria at sensitive receiver locations.

8.3.2 LNG Plant Option 2

Figures 14 to 17 show the predicted effects of emissions of NO₂ and HC from operations of Option 2 (Industrial Frame option) of the LNG Plant using the emissions data Section 7.2.2. As for Option 1, the figures show isopleths for the following:

- Maximum 1-hour average NO₂ concentrations
- Annual average NO₂ concentrations
- Maximum 1-hour average benzene concentrations
- Annual average benzene concentrations.

As for Option 1 it can be seen that the emissions are not predicted to exceed of the assessment criteria where sensitive receivers are located.

8.3.3 Shipping and tugs

LNG tankers and the tugs that will be used to assist the tankers will be sources of NO₂, SO₂ and particulate matter (PM₁₀). Figures 18 to 24 show the predicted effects of emissions of NO₂, SO₂ and PM₁₀ from the operation of LNG tankers and tugs. The figures also show the locations of two residential areas that will be the nearest neighbours to the northern boundary of the plant when built. As discussed in Section 7.3 the modelling of these emissions is complicated by the fact that the emissions are transient. This is discussed in some detail in Section 7.3. The figures show isopleths for the following:

- Maximum 1-hour average NO₂ concentrations
- Annual average NO₂ concentrations
- Maximum 1-hour average SO₂ concentrations
- Maximum 24-hour average SO₂ concentrations
- Annual average SO₂ concentrations¹⁰
- Maximum 24-hour average PM₁₀ concentrations
- Annual average PM₁₀ concentrations.

The figures show that no residential areas are predicted to exceed any of the assessment criteria for NO₂, SO₂ or PM₁₀. However some areas off-shore are predicted to exceed the WHO's (2000) 1-hour guideline of 350 µg/m³ for SO₂. (Note this is equivalent to the WHO (2005) 10-minute guideline value of 500µg/m³ – see discussion in Section 3.1.1) For safety reasons there will be an exclusion zone established around tankers during loading and these predicted exceedances are unlikely to result in any sensitive receptors (e.g. fishing vessels) experiencing concentrations above the assessment criteria.

8.3.4 Cumulative effects of the LNG Plant and shipping

In onshore winds there is the potential that emissions from tankers and tugs could carry emissions from shipping across the LNG Plant and result in cumulative effects inland and downwind of the LNG Plant. The LNG Plant is not a significant source of SO₂ or PM₁₀ so the only common emissions for shipping and the LNG Plant is NO₂. Figures 25 and 26 show the predicted 1-hour and annual average NO₂ concentrations taking account of the cumulative effect of emissions from shipping and the

¹⁰ Note: WHO (2005) no longer refers to an annual average guideline for sulphur dioxide, however it is still useful to provide information on the annual average concentration when the Interim WHO guideline values are being used.

Option 2 LNG Plant, which is the worst-case scenario. No exceedances of the assessment criteria are predicted. Because the emissions from shipping are the dominant sources the figures appear not to show the effects of emissions from the plant, however plant emissions have been included.

9 CONCLUSIONS

This report has analysed the air quality impacts associated with a project to construct and operate an LNG Plant at State Portion 152.

The assessment has used the CALMET/CALPUFF dispersion modelling package to simulate the dispersion of all significant emissions from the project for both the construction and operational phases. The assessment indicates that there will be no exceedances of any air quality assessment criteria except for some exceedances of the WHO's 1-hour guideline (equivalent to the WHO (2005) 10-minute guideline) for SO₂ for areas in the immediate vicinity of tankers when being assisted by tugs. Since the area around LNG tankers will be subject to a safety based exclusion zone it is concluded that no significant impacts will arise as a result of exceedances of the 1-hour or 10-minute criterion close to ships.

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FIGURES

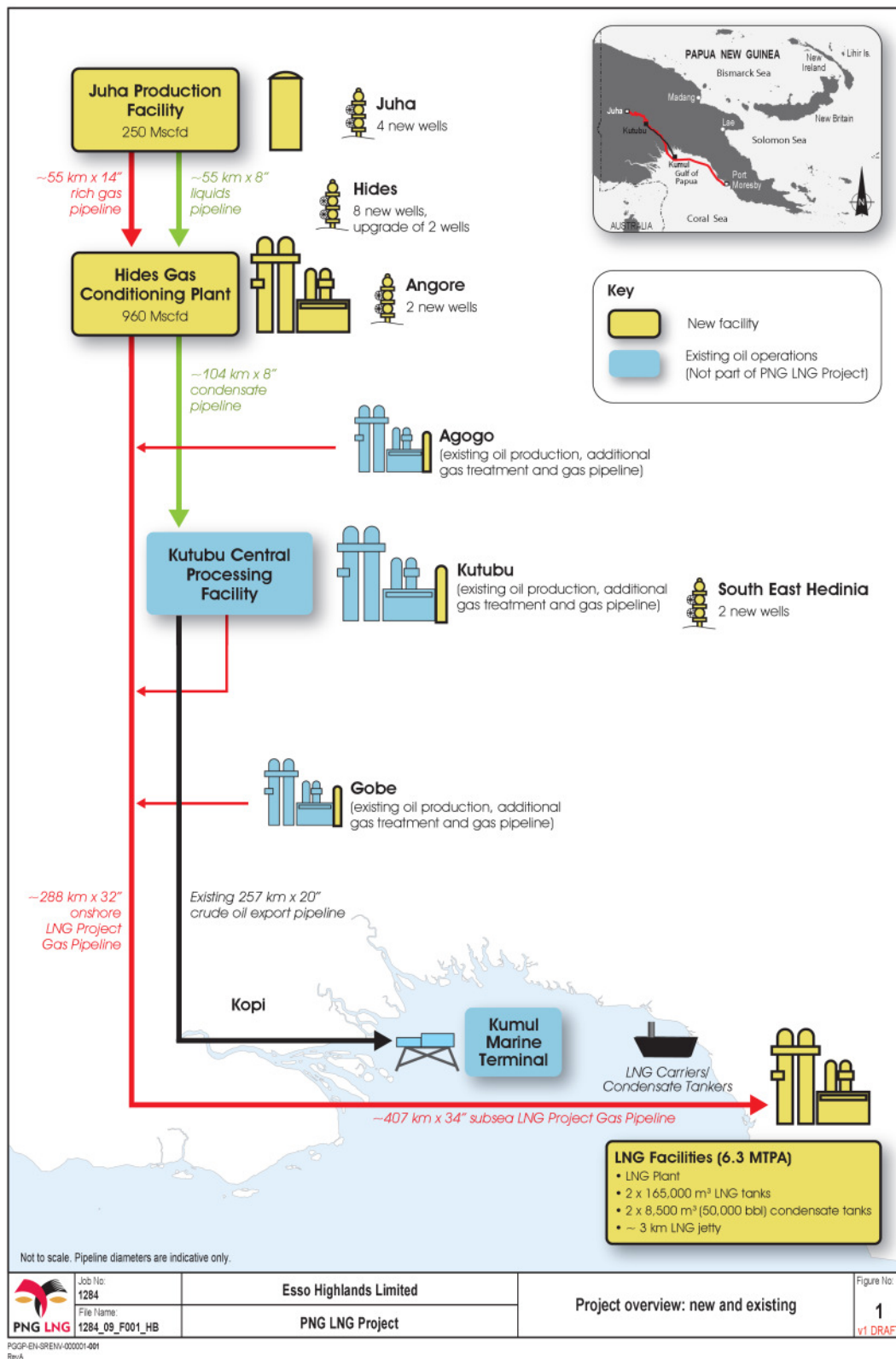
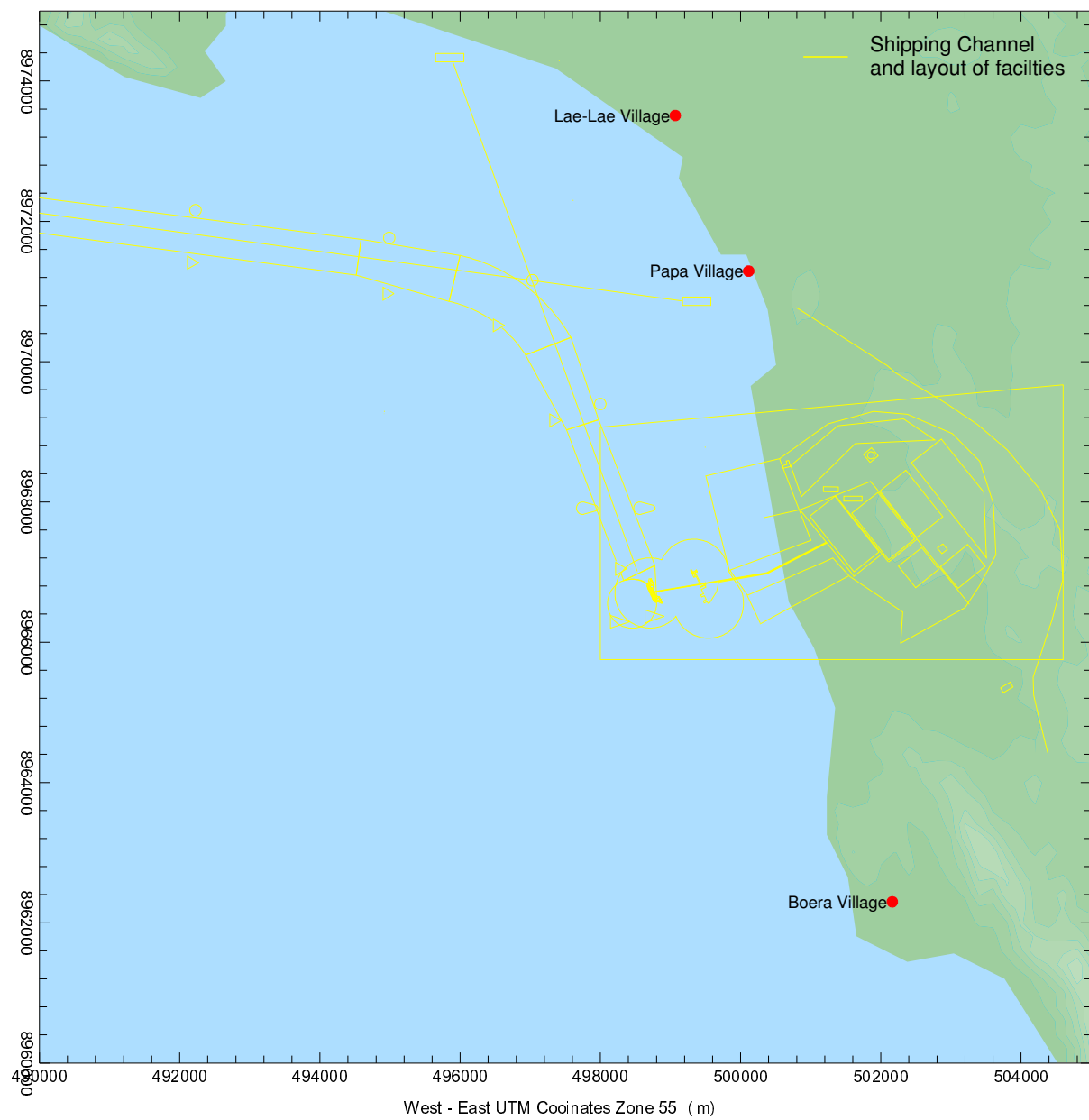
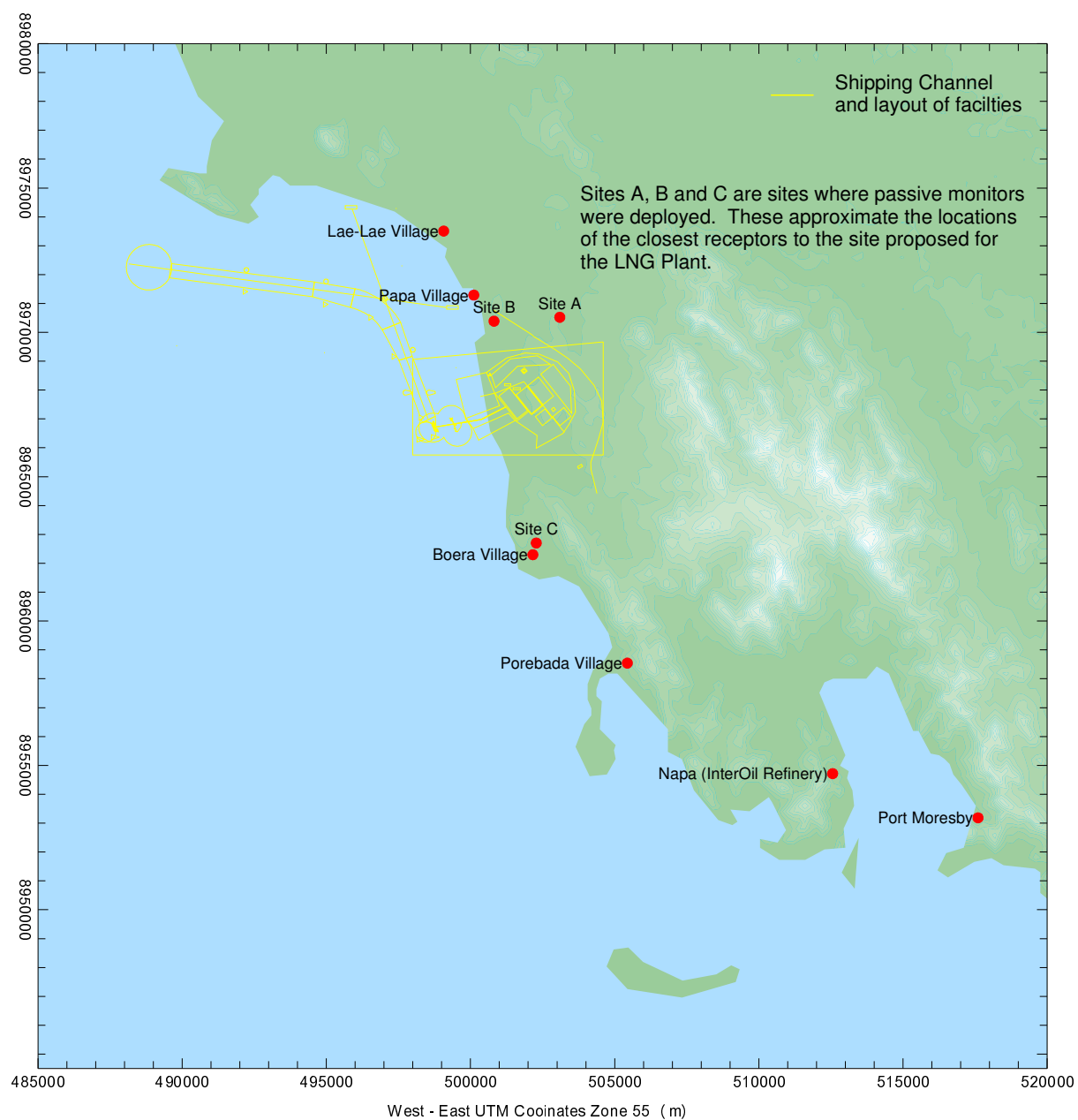


Figure 1



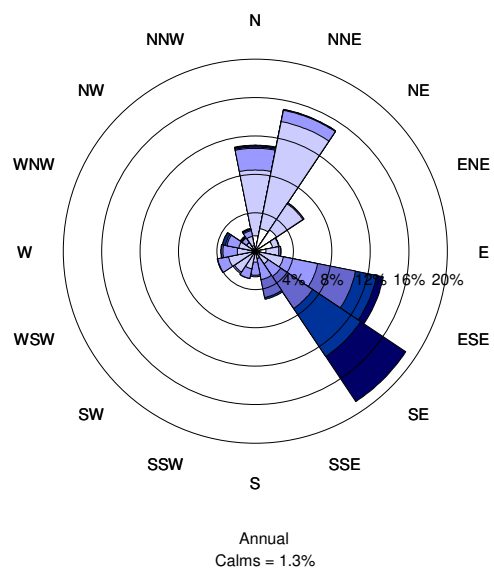
Proposed LNG Plant Layout



Locations of monitoring sites

Annual and seasonal windroses for PNGLNG08 SP152 Station 2

Note: Data incomplete. Missing
seasons not yet monitored.



Wind speed (m/s)

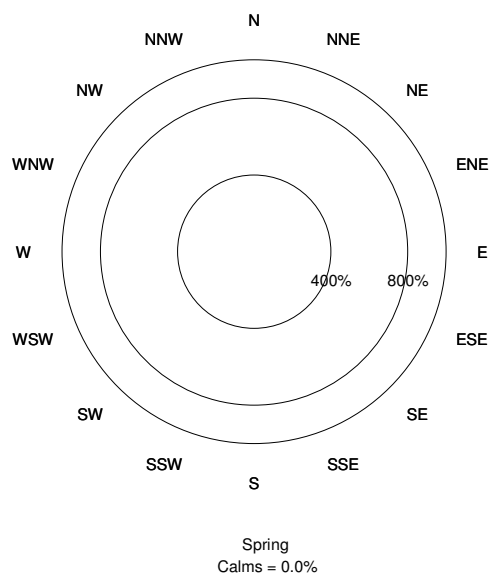
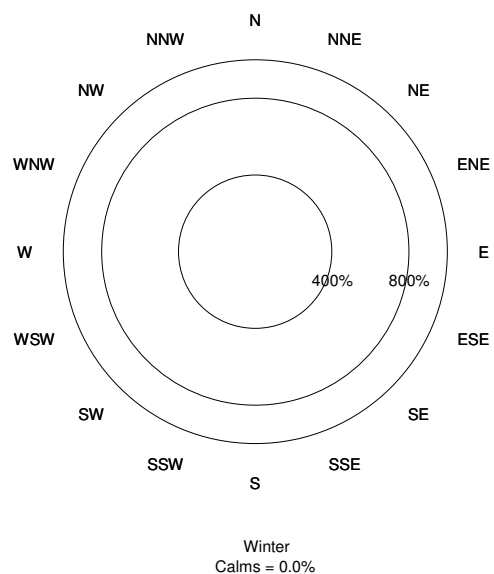
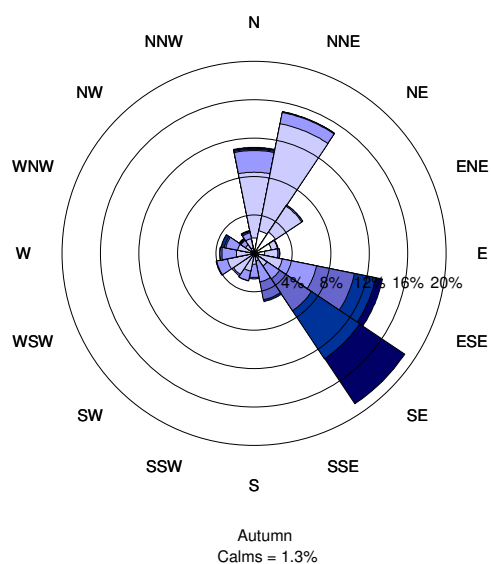
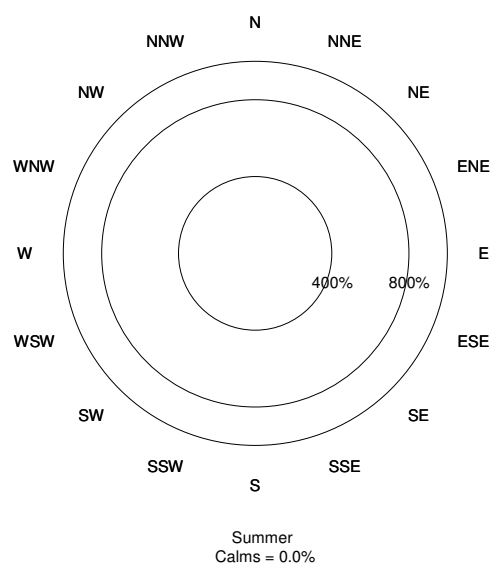
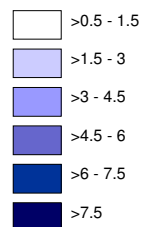


Figure 4

**Annual and seasonal windroses for LNG Plant in 2006
(from TAPM data -9.39167 deg. S, 147.0256 deg. E)**

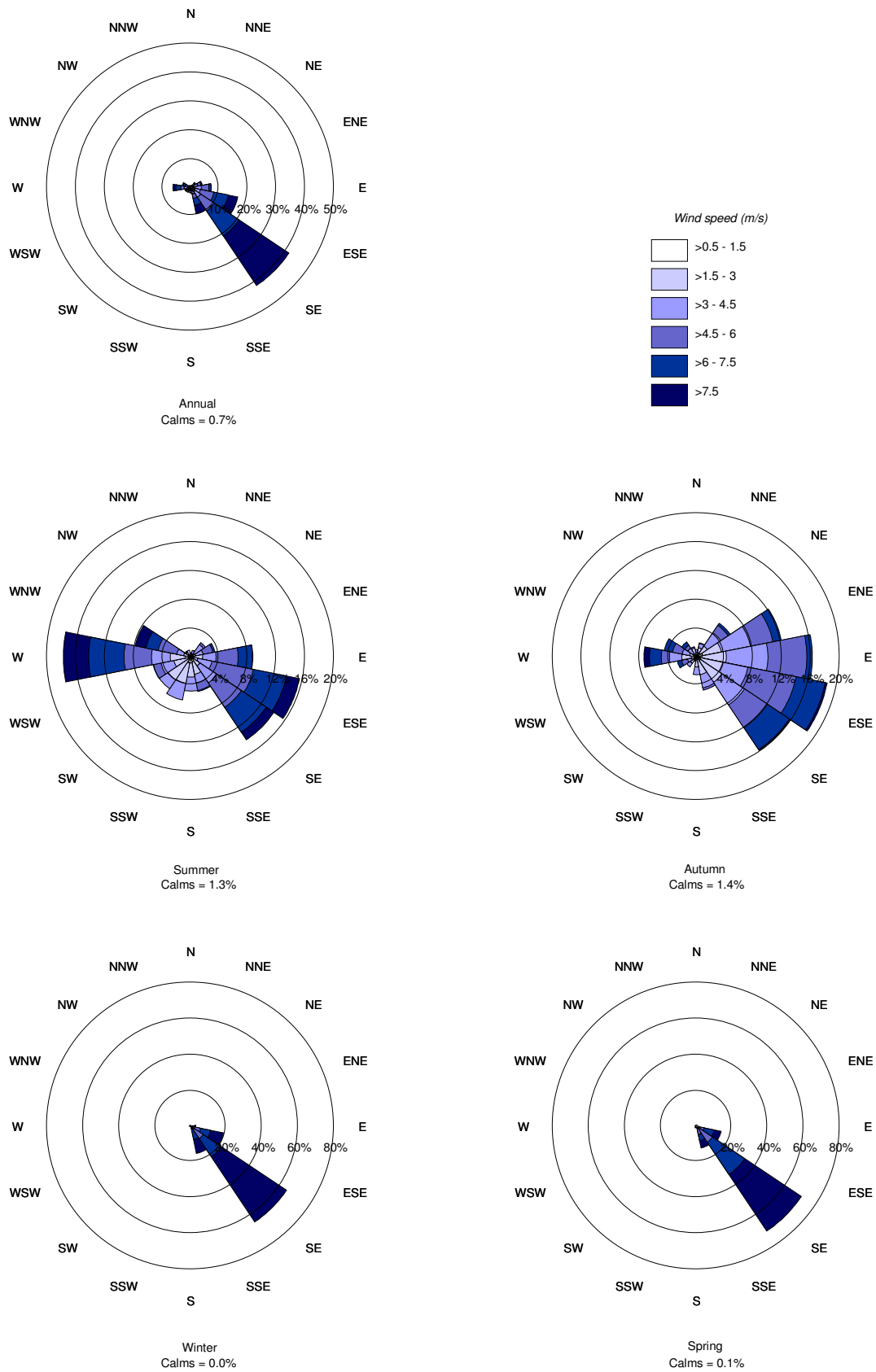


Figure 5

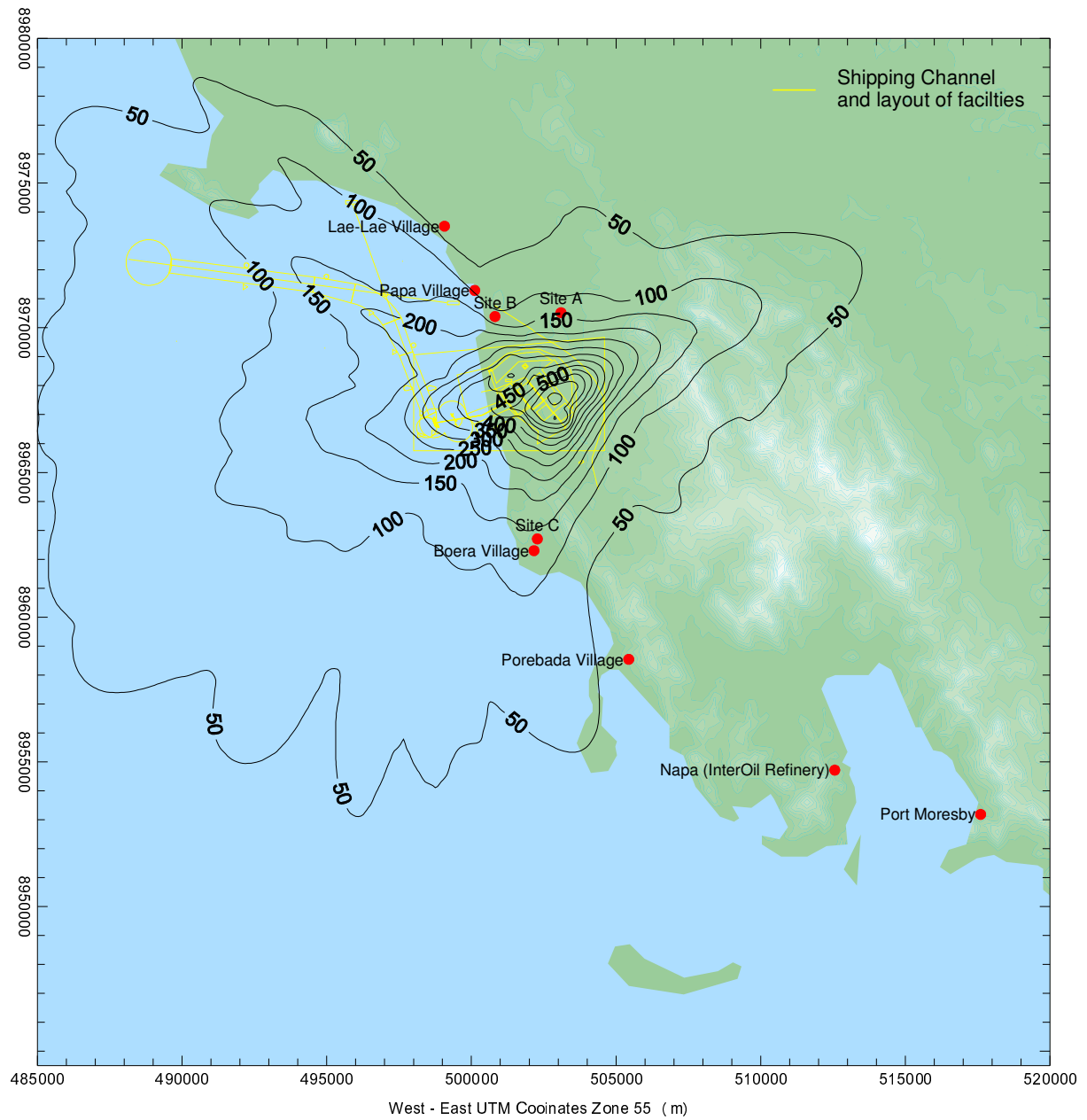
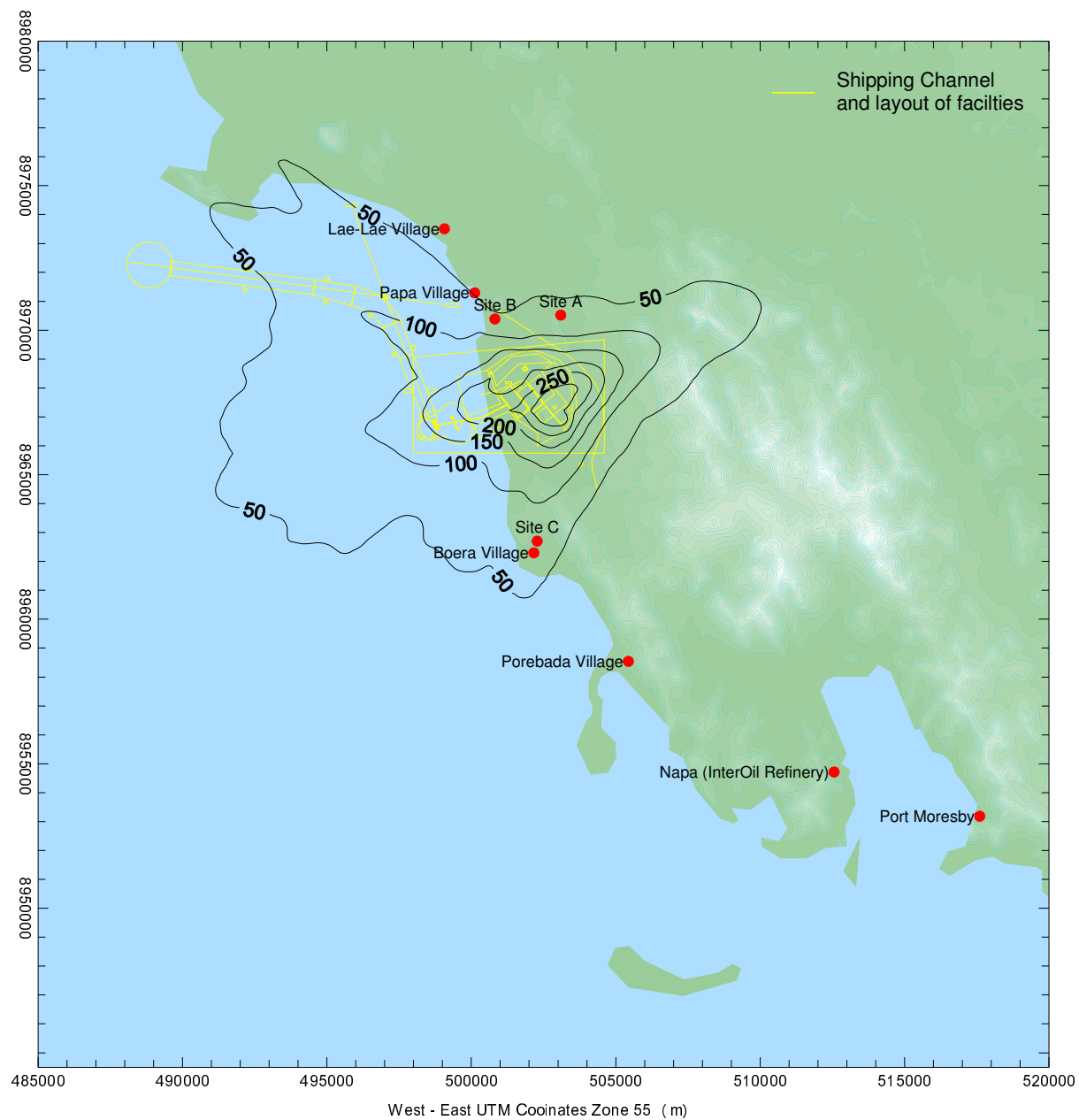


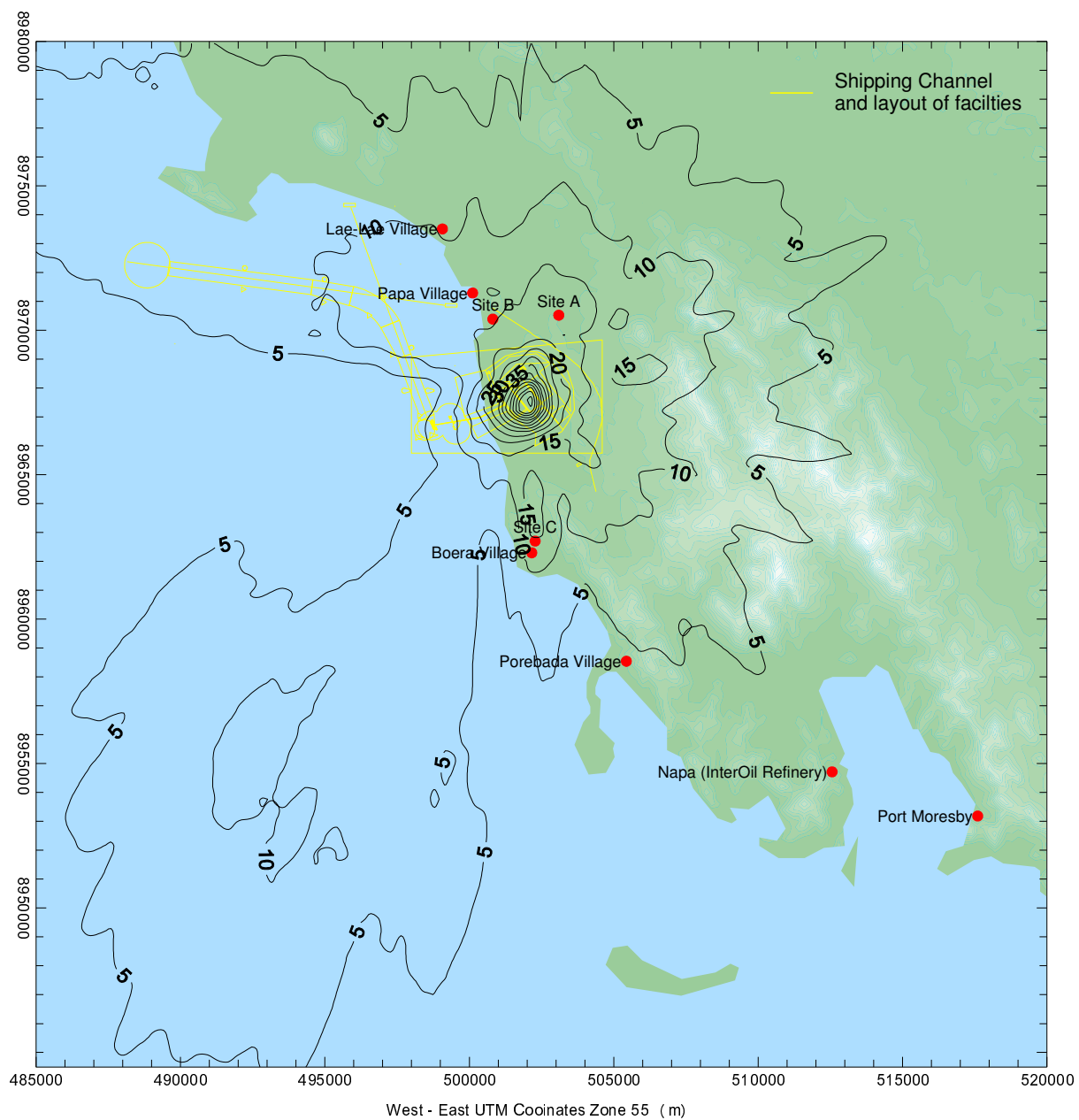
Figure 6



24-hour average WHO Interim target 1 for PM_{10} is $150 \mu g/m^3$

Predicted maximum 24-hour average PM_{10} concentrations due to
emissions from worst-case construction scenario - $\mu g/m^3$

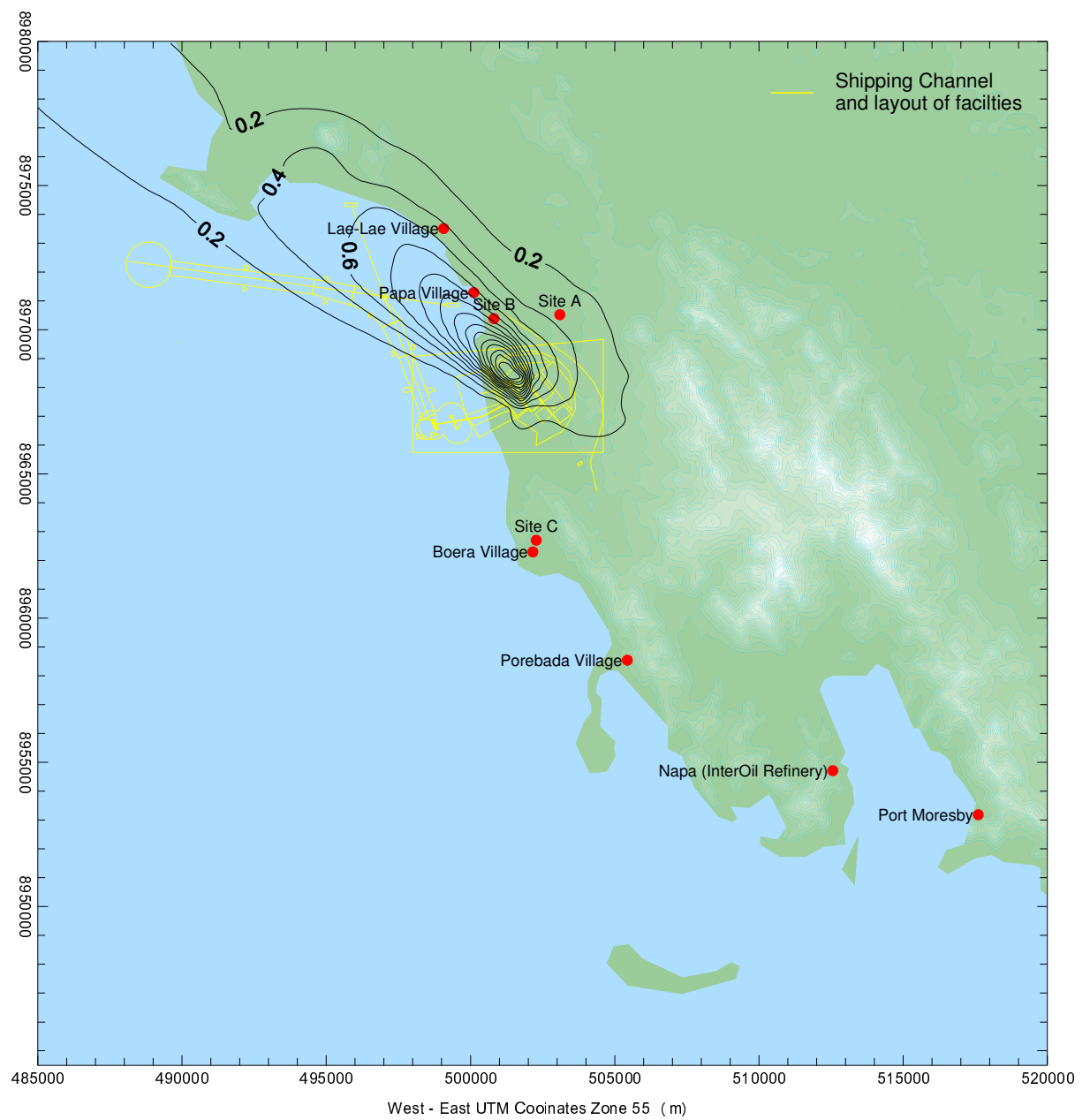
Figure 8



1-hour average WHO guideline for NO_2 is $200 \mu\text{g}/\text{m}^3$

Predicted 1-hour average NO_2 concentrations due to emissions from LNG Plant Option 1 - $\mu\text{g}/\text{m}^3$

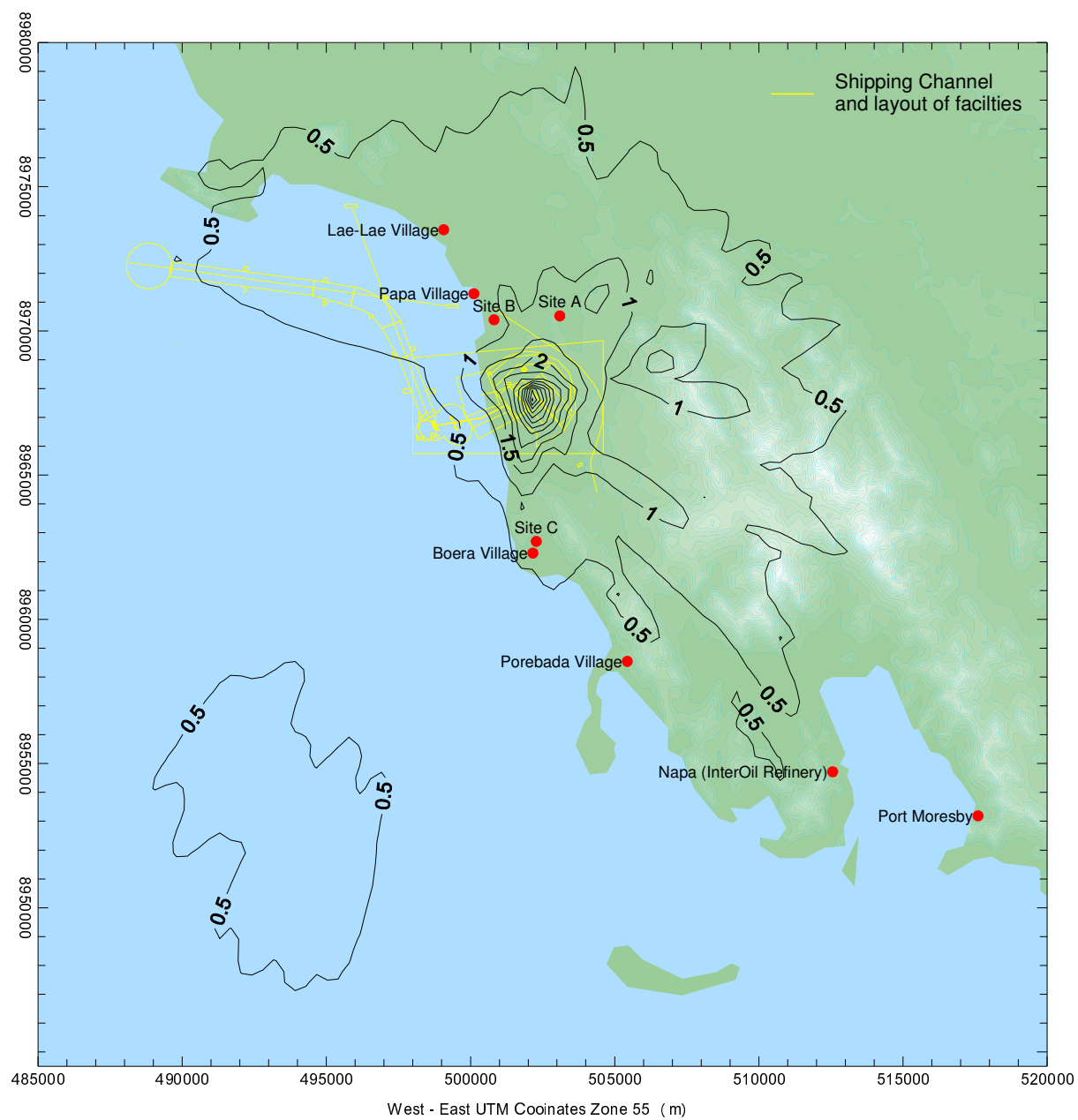
Figure 10



Annual average WHO guideline for NO_2 is $40 \mu\text{g}/\text{m}^3$

Predicted annual average NO_2 concentrations due to emissions from LNG Plant Option 1 - $\mu\text{g}/\text{m}^3$

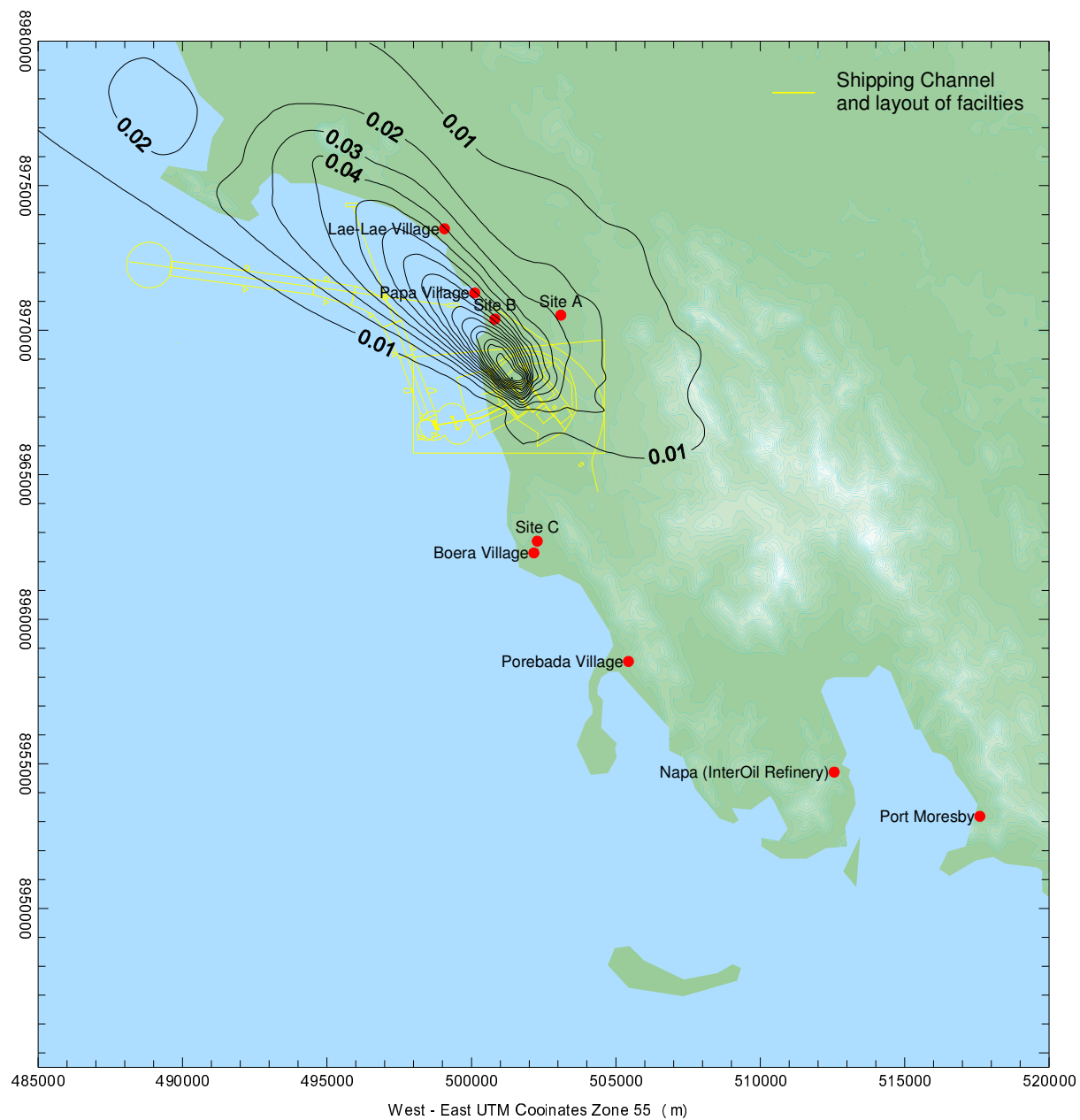
Figure 11



1-hour average TNRCC ESL for benzene is $170 \mu\text{g}/\text{m}^3$

Predicted maximum 1-hour average benzene concentrations due to emissions from LNG Plant Option 1 - $\mu\text{g}/\text{m}^3$

Figure 12



Annual average TNRCC ESL for benzene is $4.5 \mu\text{g}/\text{m}^3$

Predicted annual average benzene concentrations due to emissions from LNG Plant Option 1 - $\mu\text{g}/\text{m}^3$

Figure 13

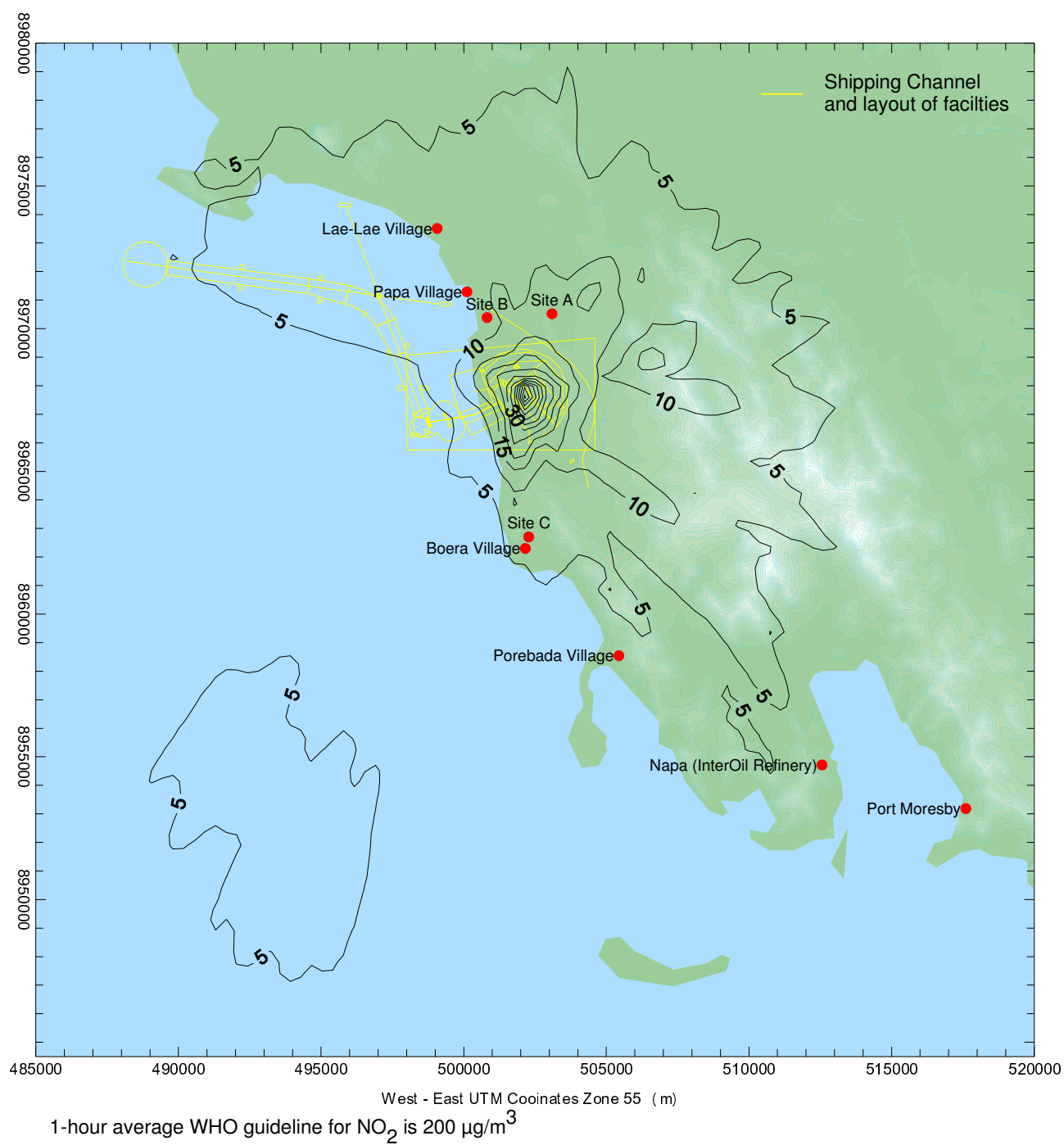
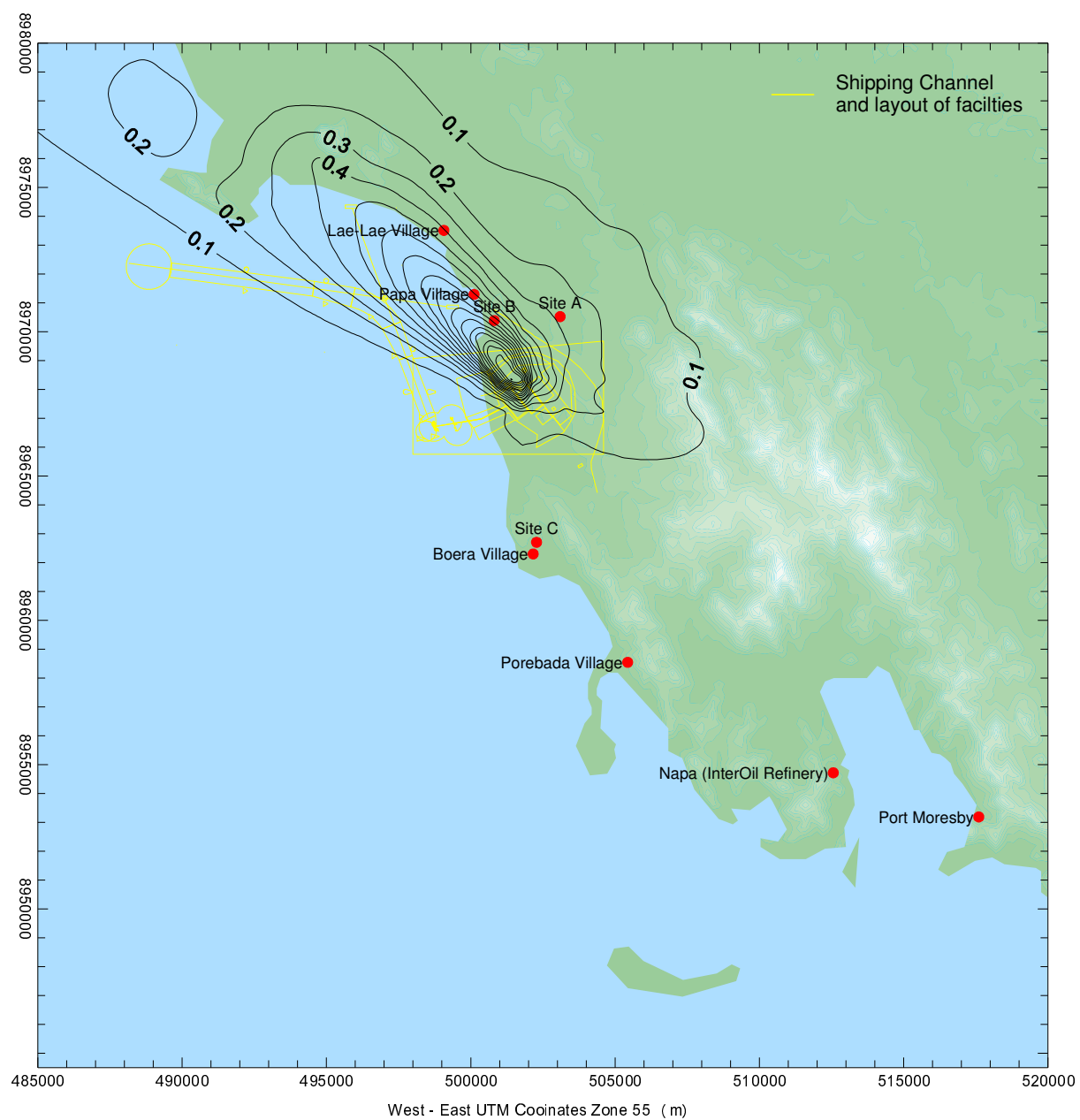


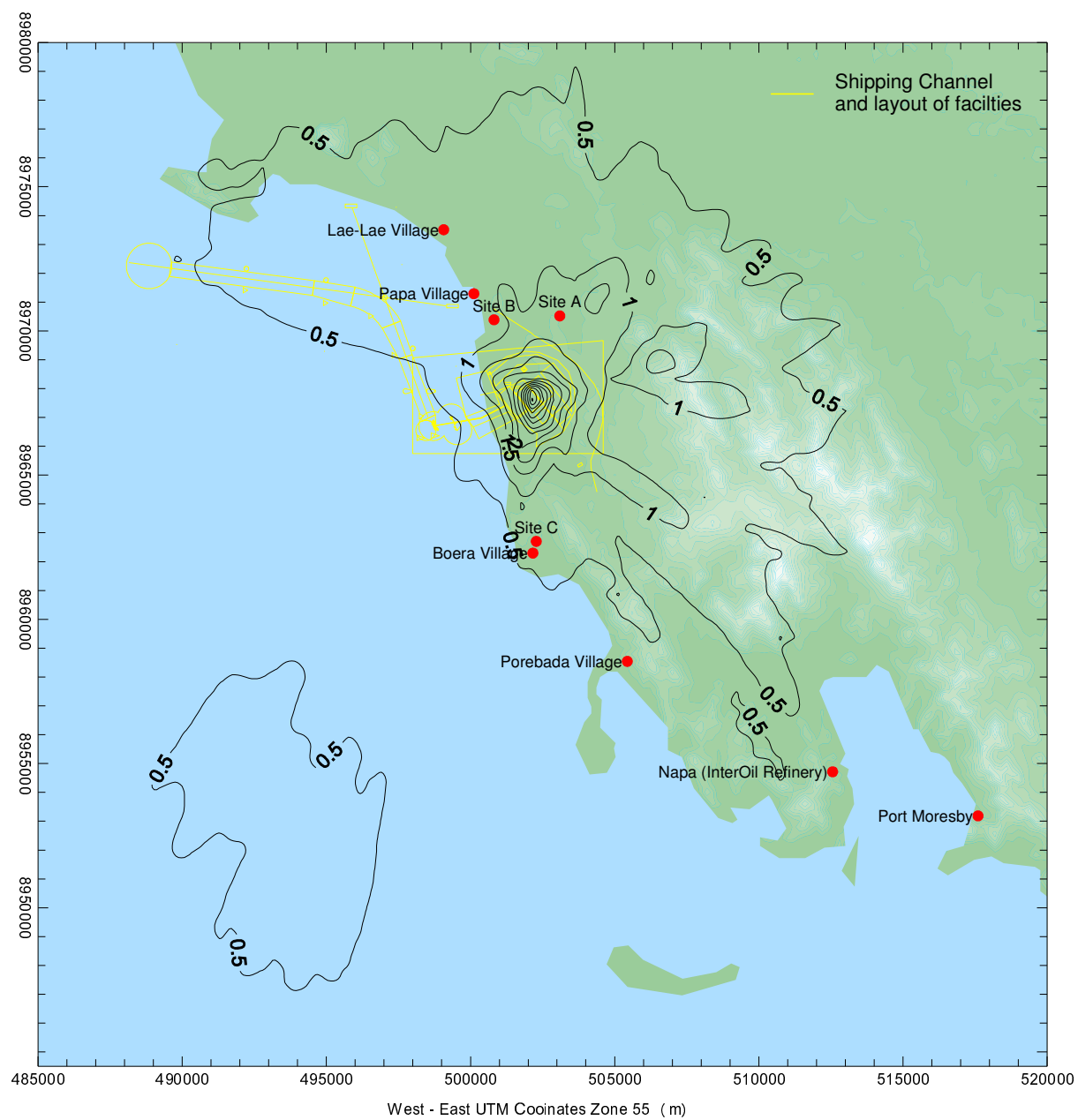
Figure 14



Annual average WHO guideline for NO_2 is $40 \mu\text{g}/\text{m}^3$

Predicted annual average NO_2 concentrations due to emissions from LNG Plant Option 2 - $\mu\text{g}/\text{m}^3$

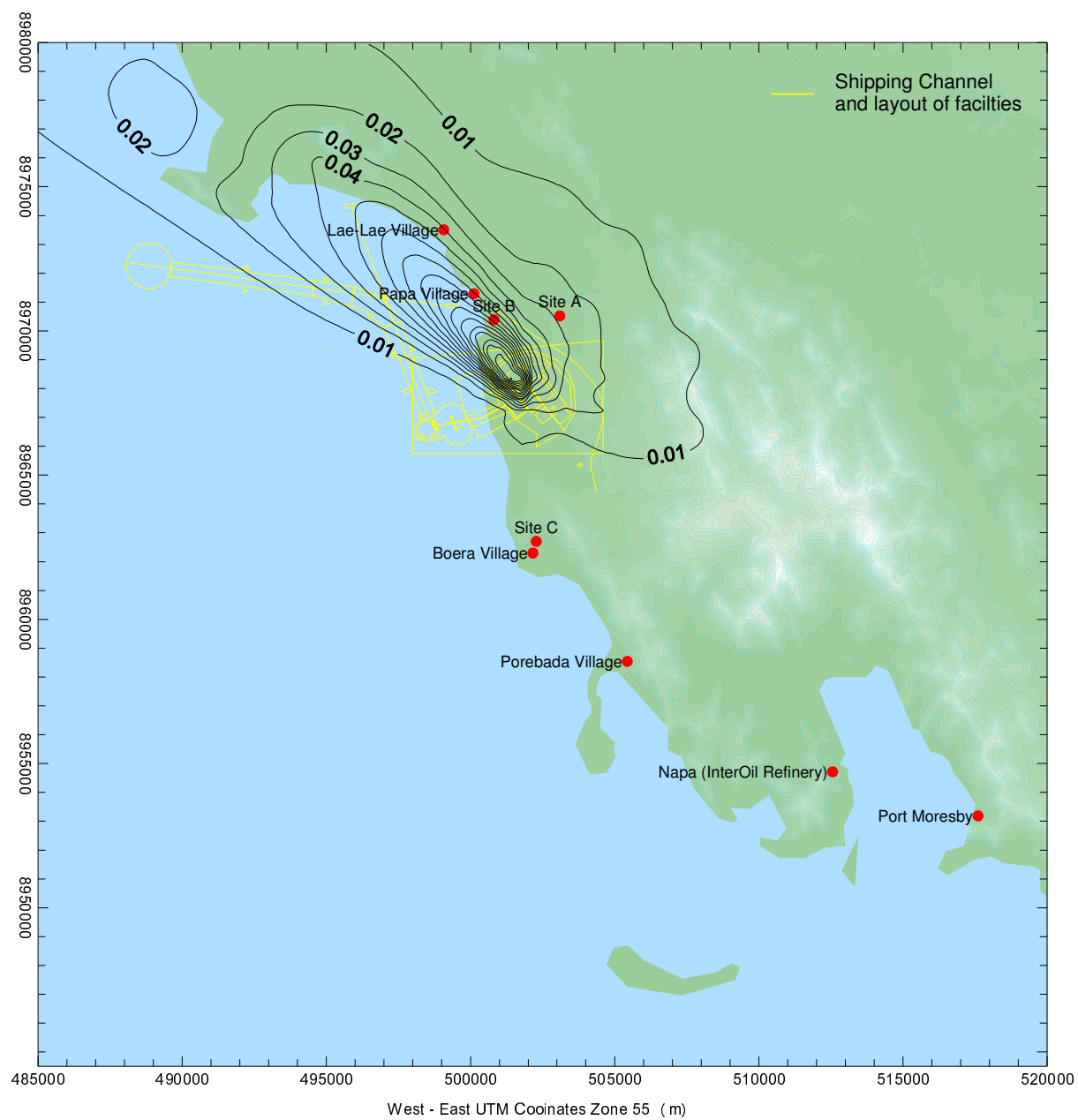
Figure 15



1-hour average TNRCC ESL for benzene is $175 \mu\text{g}/\text{m}^3$

Predicted maximum 1-hour average benzene concentrations due to emissions from LNG Plant Option 2 - $\mu\text{g}/\text{m}^3$

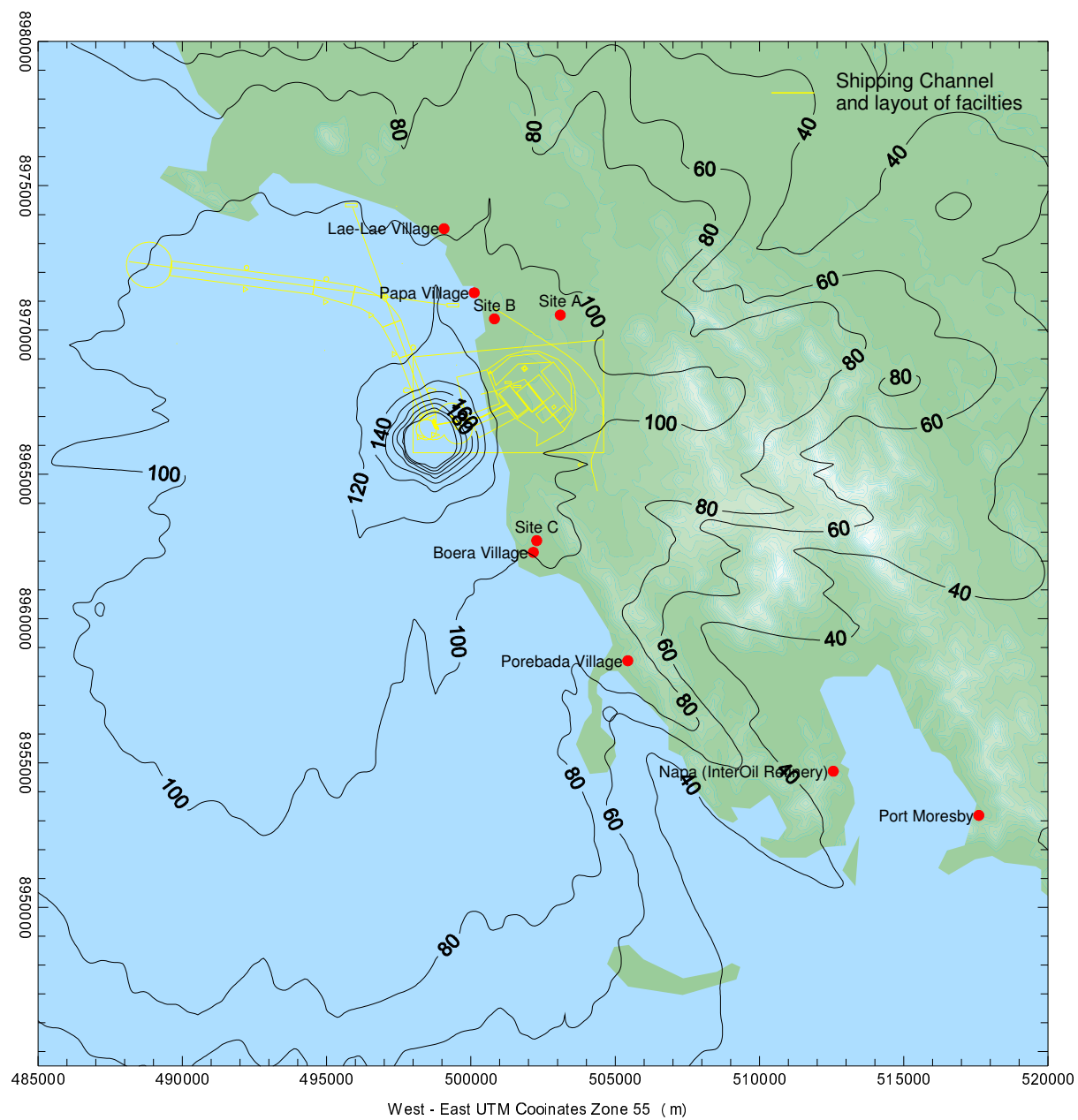
Figure 16



Annual average TNRCC ESL for benzene is $4.5 \mu\text{g}/\text{m}^3$

Predicted annual average benzene concentrations due to emissions from LNG Plant Option 2 - $\mu\text{g}/\text{m}^3$

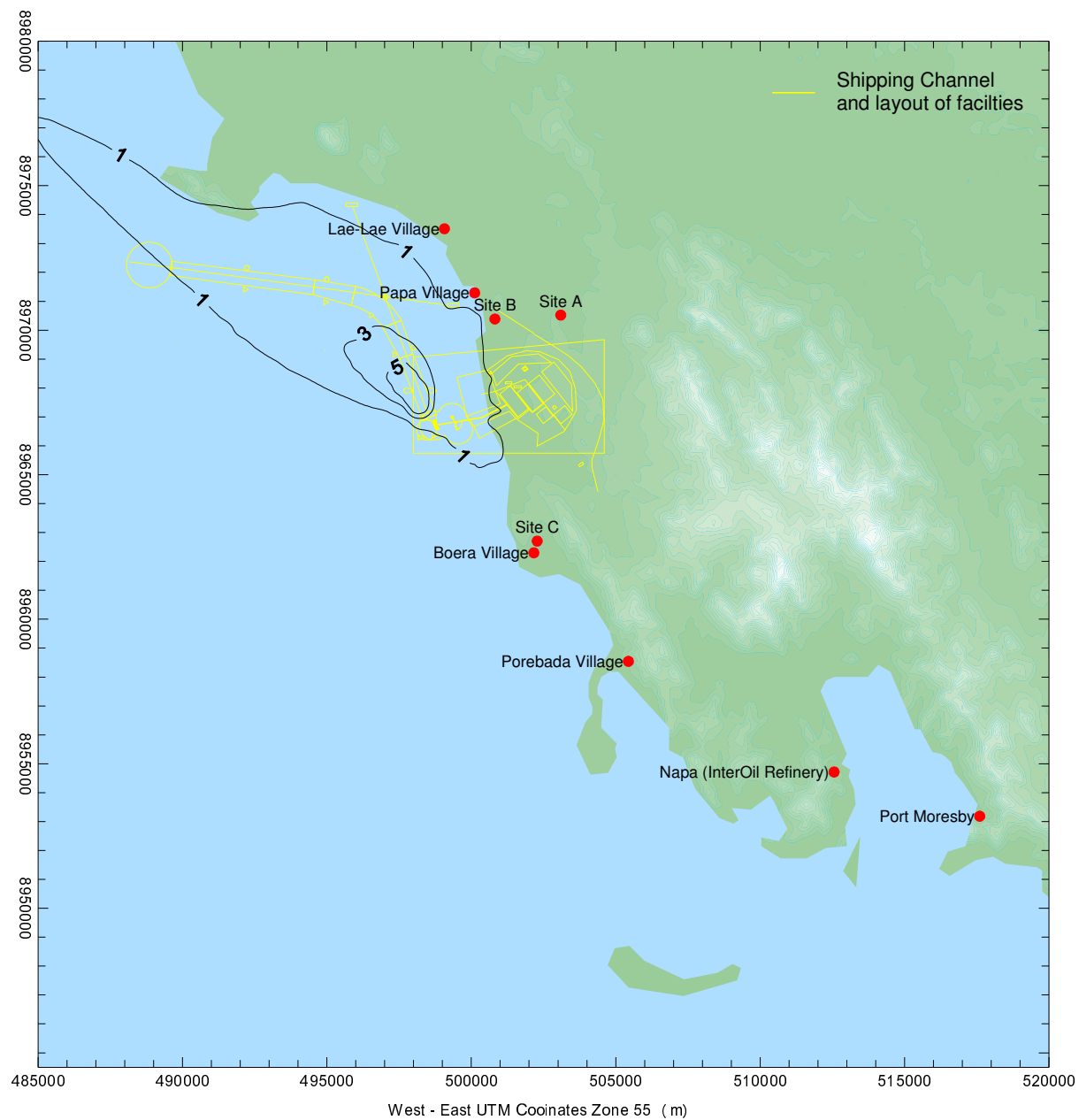
Figure 17



1-hour average WHO guideline for NO_2 is $200 \mu\text{g}/\text{m}^3$

Predicted maximum 1-hour average NO_2
concentrations due to emissions from from shipping - $\mu\text{g}/\text{m}^3$

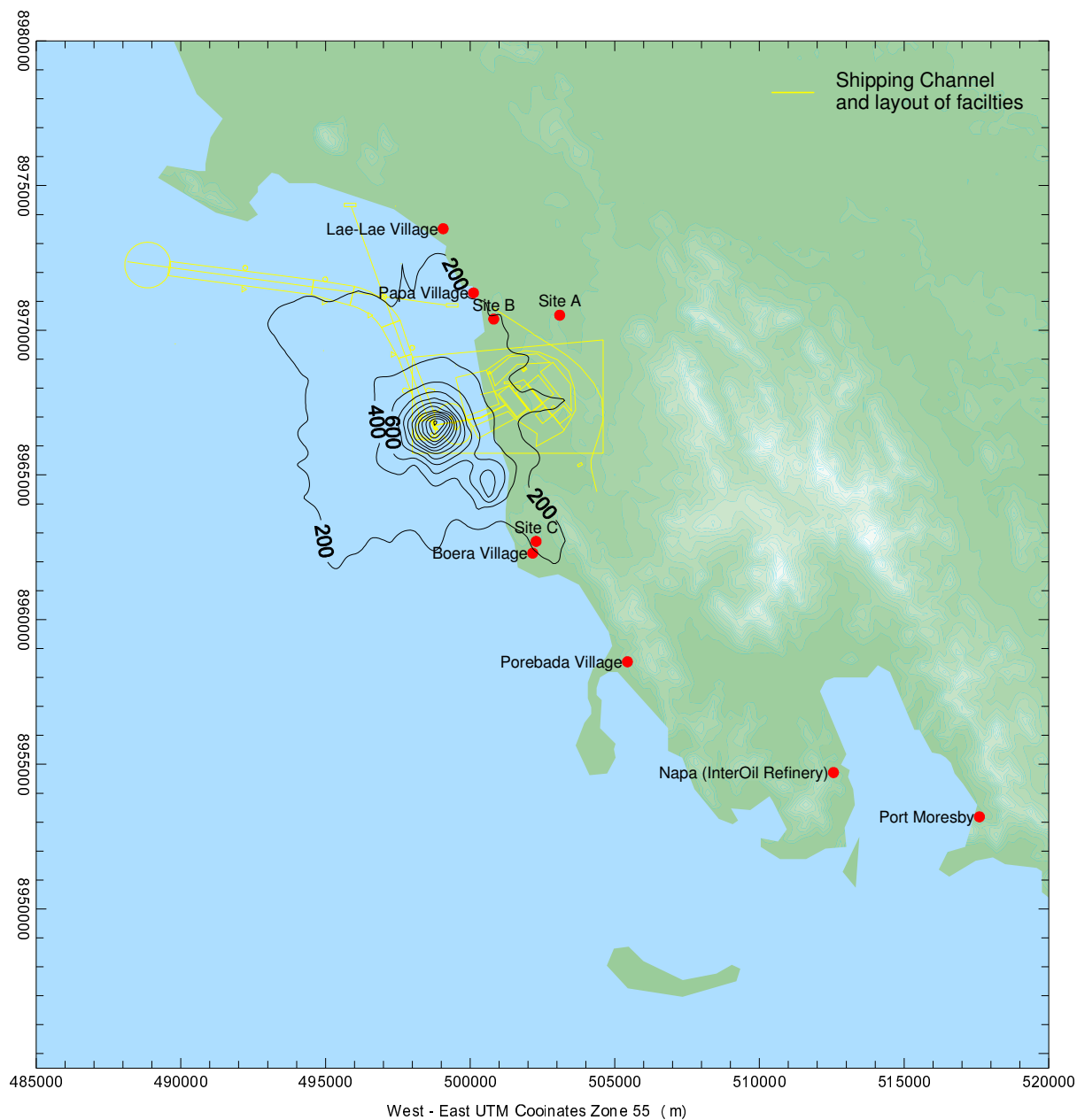
Figure 18



Annual average WHO guideline for NO_2 is $40 \mu\text{g}/\text{m}^3$

Predicted annual average NO_2
concentrations due to emissions from shipping - $\mu\text{g}/\text{m}^3$

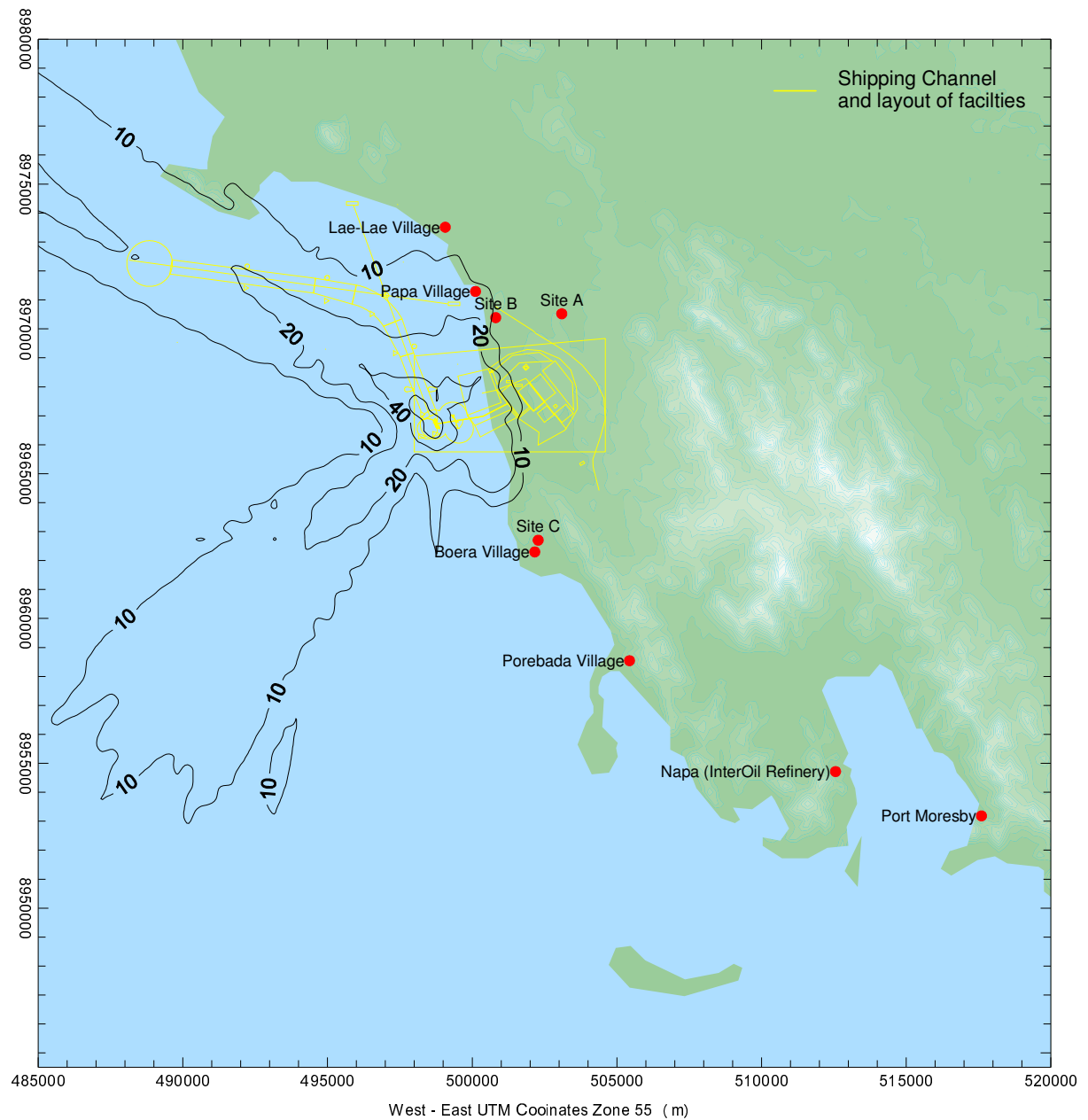
Figure 19

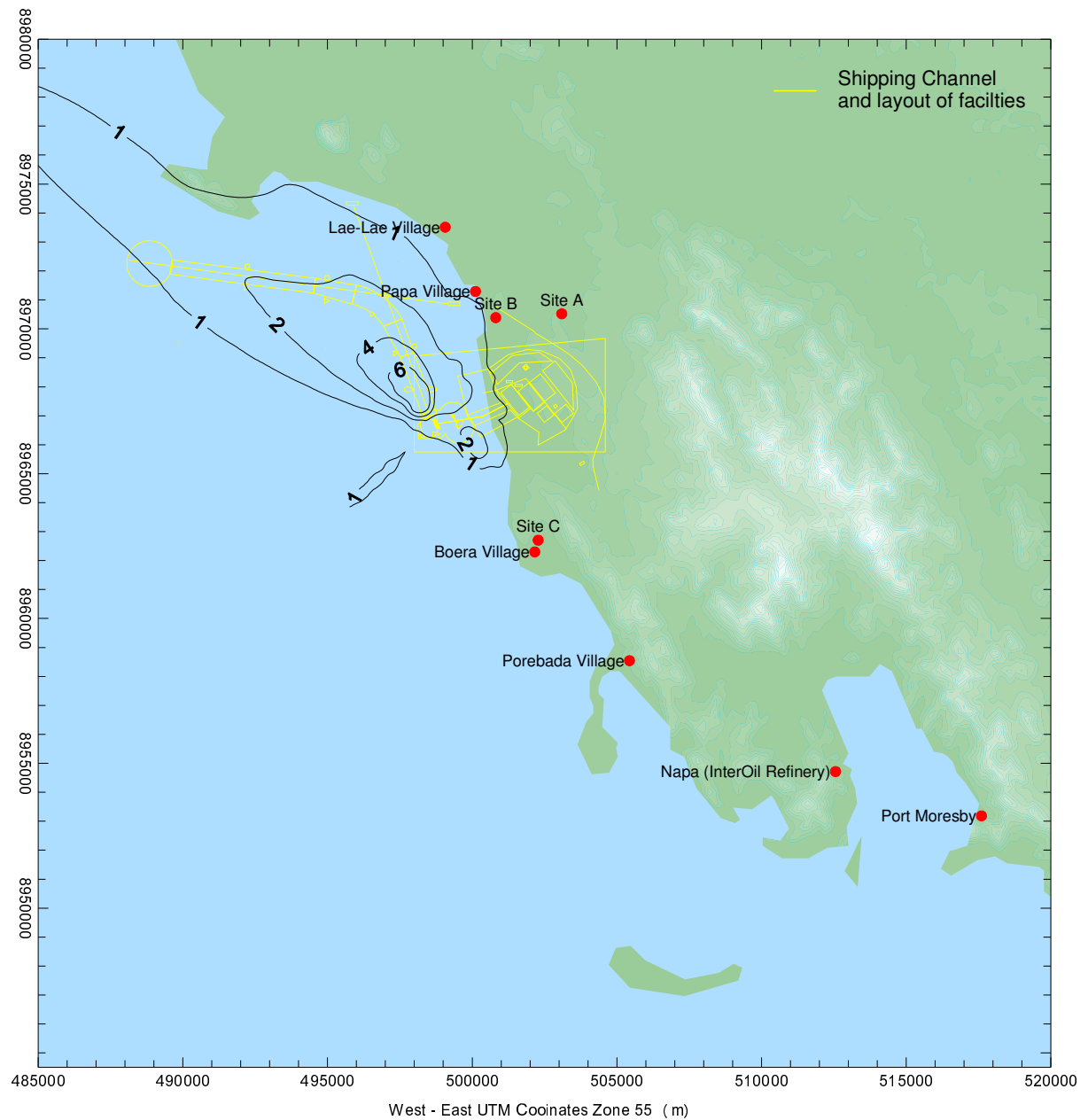


WHO (2005) guideline for SO_2 is $500 \mu\text{g}/\text{m}^3$ 10-minute average which is equivalent to $350 \mu\text{g}/\text{m}^3$ 1-hour average

Predicted maximum 1-hour average SO_2 concentrations due to emissions from shipping - $\mu\text{g}/\text{m}^3$

Figure 20

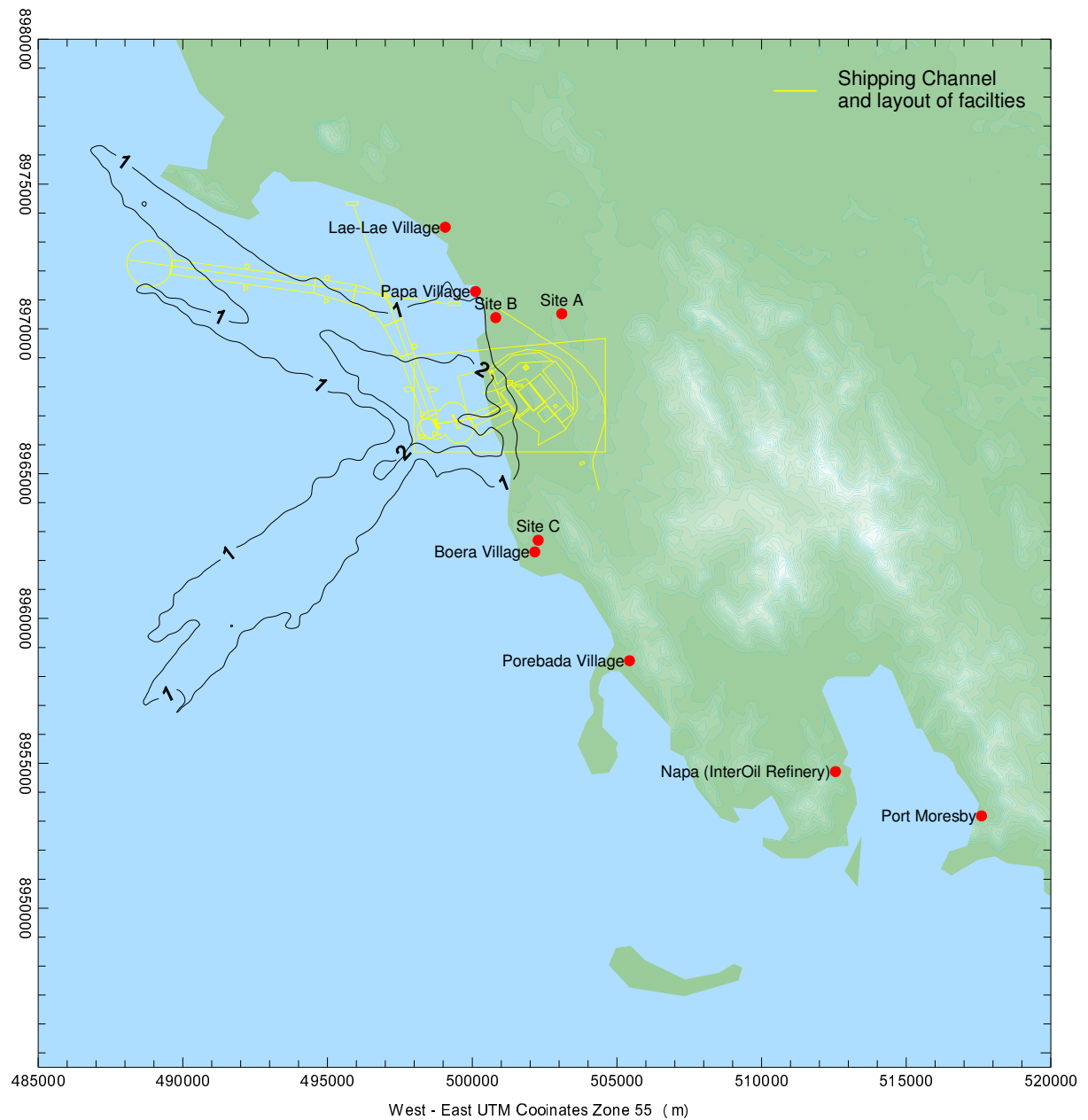




Annual average WHO (2000) guideline for SO_2 is 40 to 60 $\mu\text{g}/\text{m}^3$ (withdrawn in 2005 document see Section 3.1.1)

Predicted annual average SO_2 concentrations due to emissions from shipping - $\mu\text{g}/\text{m}^3$

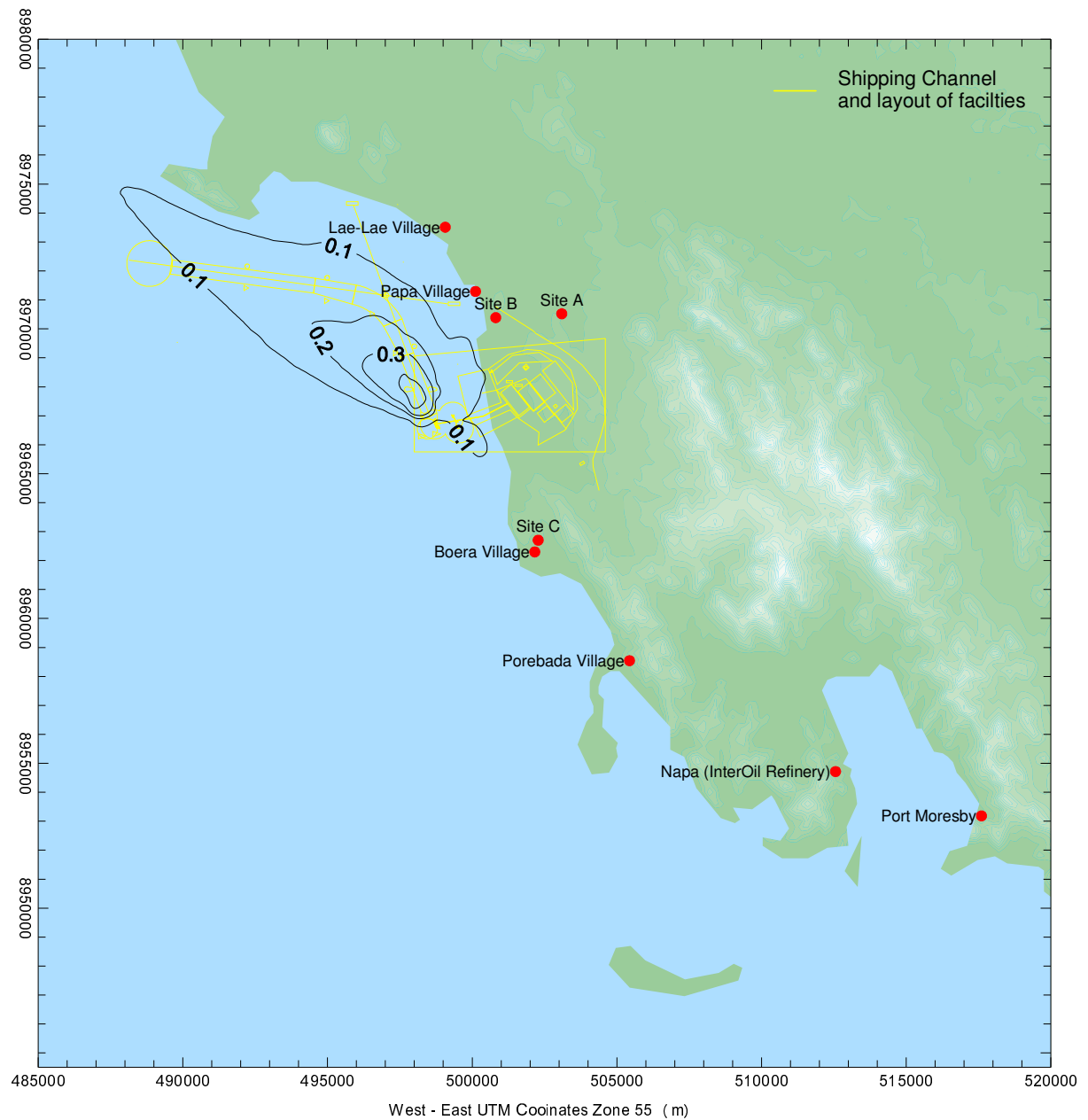
Figure 22



24-hour average WHO Interim target 1 guideline for PM_{10} is $150 \mu g/m^3$

Predicted maximum 24-hour average PM_{10} concentrations due to emissions from shipping - $\mu g/m^3$

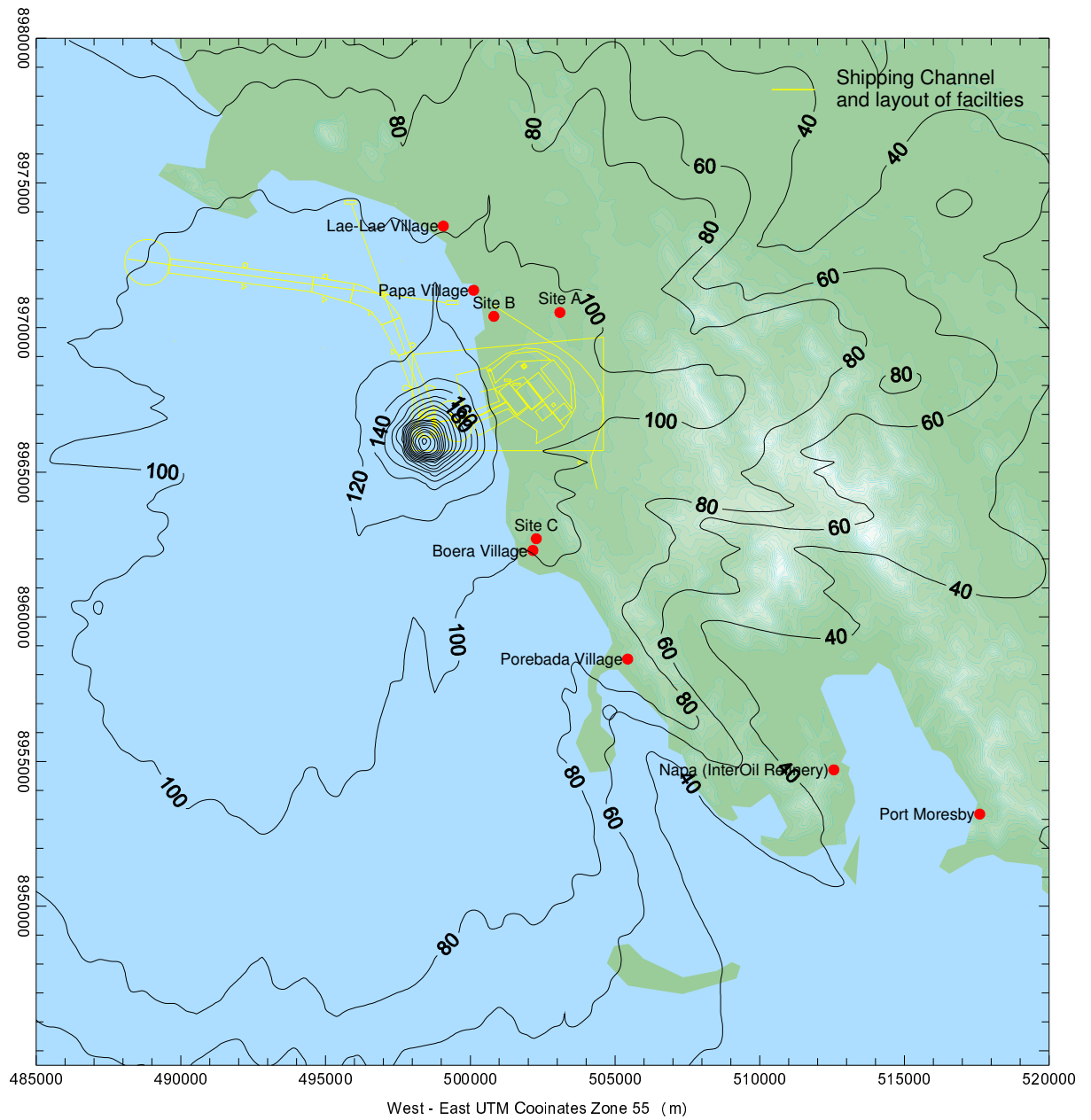
Figure 23



Annual average WHO guideline Interim target 1 for PM_{10} is $70 \mu\text{g}/\text{m}^3$

Predicted annual average PM_{10} concentrations due to emissions from shipping - $\mu\text{g}/\text{m}^3$

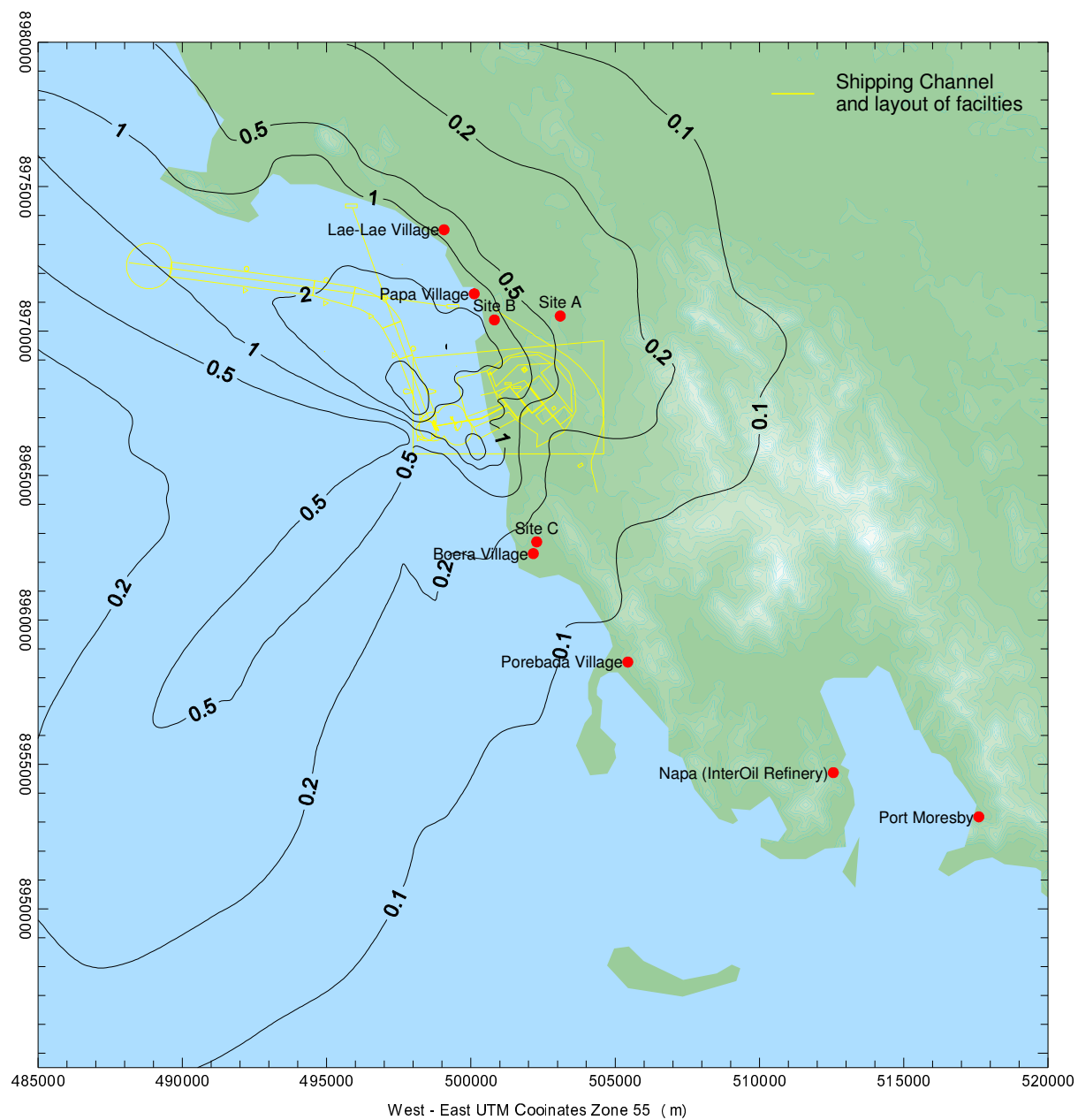
Figure 24



1-hour average WHO guideline for NO_2 is $200 \mu\text{g}/\text{m}^3$

Predicted maximum 1-hour average cumulative NO_2
concentrations due to emissions from the LNG Plant (worst-case i.e. Option 2) and from shipping - $\mu\text{g}/\text{m}^3$

Figure 25



Annual average WHO guideline for NO_2 is $40 \mu\text{g}/\text{m}^3$

Predicted annual average cumulative NO_2
concentrations due to emissions from the LNG Plant (worst-case i.e. Option 2) and from shipping - $\mu\text{g}/\text{m}^3$

Figure 26