FLARING AIR QUALITY STUDY

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1. INTRODUCTION

1.1 PROJECT DETAILS

Perdaman Chemicals and Fertilisers Pty Ltd (OWNER) are developing the world's largest gas stream ammonia-urea plant with a production capacity of 2.14 MMTPA. The plant, called Project Ceres, will be located within the Burrup Strategic Industrial Area, Burrup Peninsula, approximately 10 km from Dampier and 20 km north-west of Karratha on the North West coastline of Western Australia. The Project Ceres will produce Urea utilizing local natural gas, using innovative and low emissions technologies and will be Australia's first Urea Export Project.
The Project can be mainly divided into four sections:

1. The Syngas Block consists of three portions: Reforming, Shift and CO_2 Removal. This converts the natural gas to a high purity syngas suitable for conversion to ammonia.
2. The Product Block takes clean syngas and converts this to ammonia. The ammonia in turn is converted to urea by addition of CO_2 (recovered from the CO_2 Removal section). The urea is concentrated and granulated before dispatch.
3. The Utility Block delivers mainly power, oxygen, nitrogen and includes sea water treatment to produce mainly cooling water, demineralized water and boiler feed water) as well as wastewater management.
4. Logistics covers transportation of urea product from the site storage to Dampier Port via the Burrup Service Corridor, port storage and transfer to export vessels (the Dampier Bulk Liquids Berth "DBLB" can accommodate vessels up 65,000 tonnes displacement)

Saipem and Clough Joint Venture (CONTRACTOR), have been selected as the exclusive EPC contractor for the development of the Project.

1.2 SCOPE AND PURPOSE

Purpose of this study is to evaluate the impacts related to flaring activities that may happen within the plant during start-up and (planned or emergency) shutdown. In normal operation, Project is designed to avoid flaring and in general to minimize flare impacts. Accordingly, also purging of flare headers (necessary to prevent entrance of air through the flare open stack gas) is normally done using nitrogen instead of fuel gas.
Project Ceres Flare System is designed to ensure safe disposal of various process streams to atmosphere during start-up and shutdown and consists of the following flares:

- Syngas flare, located in a dedicated flare area, for the disposal of fluids containing mainly natural gas, syngas, carbon dioxide and water vapour mainly coming from the syngas block and power block.
- Ammonia Flare, located in a common derrick structure with syngas flare, for the disposal of ammonia vapours (to be segregated by other released stream potentially contaminated with CO_2 to minimise the risk of carbamate formation) coming from the ammonia synthesis loop and the ammonia refrigeration circuit.
- Ammonia storage tank flare, located in the ammonia storage area, is dedicated to ammonia releases from ammonia storage tank and relevant BOG.
- Primary urea flares (located inside urea trains area), where the MP vent and the Vacuum Vent are routed in case of granulator shutdown.

- Secondary urea flares (located inside urea trains area), for the disposal of process vent including those from various tanks as well as pure ammonia streams from safety valves in urea melt unit.

This study, relevant to flaring, have been carried out in addition to the Air Quality Study developed for Project in order to assess potential impacts related to the normal operation scenario. The present analysis have been undertaken following a specific request from the authorities (DWER) received during the presentation of the documents for the Project Work Approval under Part V of the EP Act (ref. to Ref. #7 and Ref. #8)

1.3 DEFINITIONS

PROJECT	PROJECT CERES (Plant to be supplied, erected and commissioned by CONTRACTOR under the CONTRACT)
OWNER	PERDAMAN CHEMICALS AND FERTILIZERS PTY LTD.
CONTRACTOR	SAIPEM CLOUGH JOINT VENTURE

1.4 ABBREVIATIONS

AEGL	Acute Exposure Guideline Level
AHD	Australian Height Datum
AQS	Air Quality Standard
CO	Carbon monoxide
DWER	Department of Water and Environmental Regulation
EP Act	Environmental Protection Act 1986
EPA	Environmental Protection Authority (WA)
EPC	Engineering, Procurement and Construction
EPSG	European Petroleum Survey Group
ERD	Environmental Review Document
ERPG	Emergency Response Planning Guideline
GLC	Ground Level Concentration
MAC	Murujuga Aboriginal Corporation
MTPA	Metric Tonnes per year

NEPM	National Environment Protection Measures
NSW	New South Wales
NO_X	Oxides of Nitrogen
NO_2	Nitrogen Dioxide
O_3	Ozone
PM	Particulate Matter
PM10	Particulate Matter with equivalent aerodynamic diameter of 10 µm or less
ppm	Part per Million (volume)
SCJV	Saipem & Clough JV
SO_2	Sulphur dioxide
tkFT	ThyssenKrupp FT
WA	Western Australia

2. REFERENCE DOCUMENTS

2.1 ENVIRONMENTAL AUTHORIZATION DOCUMENTS

#1. Environmental Review Document (ERD), Cardno, 16 March 2020
#2. EPA Assessment Report (1705)
#3. Ministerial Statement (1180)
#4. Part-V, work approval No. W6875/2023/1 Dt. 25-06-2024
#5. DWER Request For Further Information DER2023/000727 (22/11/2023)
#6. Answer to DWER Request For Further Information (21/12/2023)
#7. DWER Request For Further Information DER2023/000727 (16/02/2024)
#8. Answer to DWER Request For Further Information (19/03/2024)

2.2 REGULATORY, CODE AND STANDARDS APPLICABLE:

#9. Environmental Protection Act 1986
#10. Environmental Protection Regulations 1987
#11. Environmental Protection (NEPM UPM) Regulations 2003
#12. Emergency Response Planning Guideline (ERPG)

3. SITE LOCATION

The Project will be located within the Burrup Strategic Industrial Area (SIA) on the Burrup Peninsula, approximately 10 km from Dampier and 20 km north-west of Karratha on the north-west coastline of Western Australia (Figure 1).

The Burrup SIA is in close proximity to the Murujuga National Park which covers an area of 4,913 ha on the Burrup Peninsula and it is adjacent to a National Heritage listed area. The area is considered to host the largest concentration of ancient rock art in the world. As such, the Project will apply effective management strategies that minimise or abate, actual or potential impacts on the environment, heritage, and cultural values of the region.

The Project will be split on two sites, namely Sites C and Site F. Process units (Ammonia Production Block, Urea and Granulation Block) and all the utilities will be located within site C.

Site F will mainly include Laboratory, chemical storage, warehouse, maintenance and administration buildings.

Figure *2* shows project footprint, site F and Site C position as well as it provides the indication of the extension of the close National Heritage listed area.

Figure 1. Position of the Project.

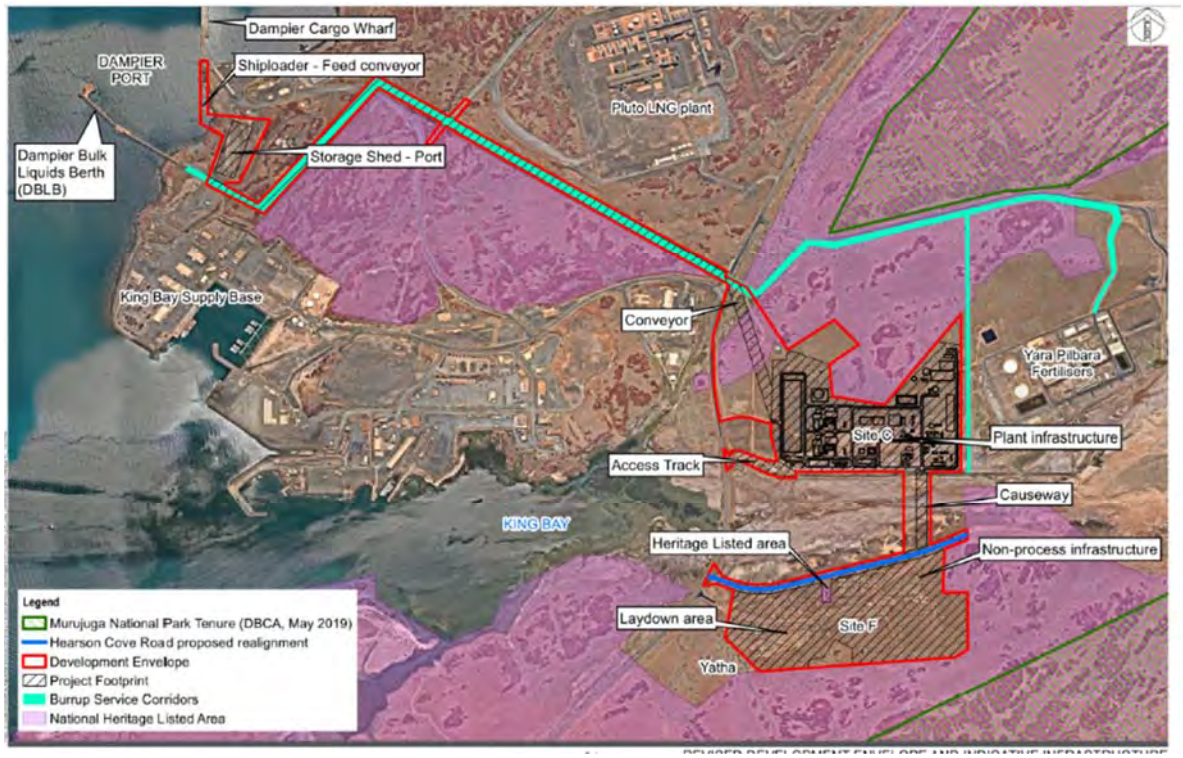

Figure 2. Project footprint.

4. PLANT DESCRIPTION

Project Ceres is designed to convert 130 terajoules per day of natural gas, supplied by Woodside LNG facility as feedstock, into approximately two million tonnes of urea annually. Produced Urea will be transferred by overland conveyor to the Port of Dampier to be exported.

The Project consists of these main functional units:

- Ammonia Plant – Unit 2500 (one train with a production capacity of 3,500 tpd, Haldor Topsøe SynCOR technology)
- Urea Melt & Granulation Plants - Units 2600 & 2700 (two trains with a production capacity of 3,100 tpd each based on Snamprogetti and tkFT technology)
- Utility Block (including Power Generation, Air Separation Unit, Cooling unit)
- Infrastructure, logistics, buildings

5. ASSESSMENT CRITERIA

Compliance with Air Quality criteria has been verified by adopting a calculation domain large enough to consider the maximum GLCs due to flaring operations.

5.1 AIR QUALITY CRITERION

Given that flaring analysis refers to short-term transitory events associated with upset situations, the set of air quality standards applicable for normal operation cannot be considered the suitable reference. It is common practice to refer instead to the public exposure guidelines[1] that are intended to predict how members of the general public would be affected if they are exposed to a particular hazardous chemical in an emergency response situation. Accordingly, the Emergency Response Planning Guidelines (ERPGs) are considered as reference for the present study.
ERPGs estimate the concentrations at which most people will begin to experience health effects if they are exposed to a hazardous airborne chemical for 1 hour. A chemical may have up to three ERPG values[2], each of which corresponds to a specific tier of health effects. The three ERPG tiers are defined as follows:

- ERPG-3 is the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.
- ERPG-2 is the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.
- ERPG-1 is the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient adverse health effects or without perceiving a clearly defined objectionable odour.

Tier 2 (i.e., ERPG-2) is considered in this analysis. The ERPGs for carbon monoxide (CO), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) are reported in Table 1. The original ERPG-2 values are expressed in ppm; they have been transformed in $\mu g/m^3$ at a reference temperature of 25 °C.
For particulate matter, intended as PM10, there are no acute exposure levels available. Therefore, the short-term (i.e., 24-hour) standards based on the Australian National Environmental Protection (Ambient Air Quality and Air Toxics) Measure (NEPM) are used (Table 2). This is a very conservative assumption both because reference is made to an air quality standard (that, as explained before, should be considered a reference for normal operation condition only), and because the 24-hour statistics involve a more stringent average than that defined on an hourly basis (which instead would be the appropriate reference statistic for this type of transitory scenarios).
Then, the resulting Ground Level Concentrations (GLCs) have been evaluated by comparison with the **1-hour ERPG-2 for CO, NO_2 and SO_2**, and with the **24-hour air quality standard for PM10**.

Table 1. 1-hour ERPG-2 values for CO, NO_2 and SO_2

Level (ppm)	CO	NO_2	SO_2
ppm	350	15	3
$\mu g/m^3$	400731	28211	7857

[1] https://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/resources/public-exposure-guidelines.html
[2] https://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/resources/emergency-response-planning-guidelines-erpgs.html

Table 2. Short-term air quality criteria for PM10.

Pollutant	Concentration (maximum)	Averaging period	Reference
Particulates as PM10	50 µg/m^3	24-hour	NEPM 2016

6. MODELING SYSTEM

The modelling system used for this analysis is the CALMET/CALPUFF (version 7.2.1), which is included in the list of alternative models of the U.S. EPA[3]. Moreover, the Weather Research and Forecasting (WRF[4]) model has been used to feed CALMET.

6.1 WRF

The Weather Research and Forecasting (WRF) model is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting needs. It has been developed cooperatively by NCEP (National Centers for Environmental Prediction), NCAR (National Center for Atmospheric Research), and the meteorological research community. Two main configurations exist: WRF NMM (Non-hydrostatic Mesoscale Model) and WRF ARW (Advanced Research WRF). The initial and lateral boundary conditions are provided to WRF by a larger-scale data set deriving from global models.
WRF is a complex model which requires scientific knowledge and high computational resources to be used.
The typical steps to run WRF are:

- Definition of the simulation domains (normally at least three nested domains are used) and interpolation of various terrestrial data sets to the model grids. In addition to computing latitude and longitude for every grid point, a series of interpolations of geophysical variables to the model grids is carried out (e.g., soil categories, land use category, terrain height, annual mean deep-soil temperature, monthly vegetation fraction, monthly albedo, maximum snow albedo, slope category).
- Unpacking of meteorological data in GRIB format (GRIB1 and GRIB2) and packing them into an intermediate file format.
- Horizontally interpolation the (ungribbed) meteorological data onto the coarse (outer) model domain.
- Vertical interpolation of the files generated in the previous phase, creation of boundary and initial condition files. Some consistency checks are also performed during this phase.

After all the previous points, the simulation of the WRF meteorological model can start. The simulations require powerful Linux servers and can be done, for example, by means of cloud computing.

[3] https://www.epa.gov/scram/air-quality-dispersion-modeling-alternative-models
[4] https://www.mmm.ucar.edu/weather-research-and-forecasting-model

6.2 CALMET

CALMET[5] is a diagnostic meteorological model which reconstructs the 3D wind and temperature fields starting from meteorological measurements, orography, and land use data. Besides the wind and temperature fields, CALMET determines the 2D fields of micro meteorological variables needed to carry out dispersion simulations (mixing height, Monin Obukhov length, friction velocity, convective velocity and others).
The diagnostic wind field module uses a two-step approach for the computation of the wind field (Figure 3). In the first step an initial guess wind field is adjusted for kinematic effects of terrain, slope flows, and terrain blocking effects to produce a Step 1 wind field. The second step consists in an objective analysis procedure that introduces observational data into the Step 1 wind field to produce a final wind field. CALMET can optionally use the output of prognostic meteorological models such as MM5 or WRF in three different ways:

- as a replacement for the initial guess field,
- as a replacement for the Step 1 field,
- as pseudo-observations in the objective analysis procedure.

The prognostic wind fields in some cases have the advantage to better represent regional flows and certain aspects of sea breeze circulations and slope/valley circulations.
CALMET needs as input data, meteorological observations at surface level and upper air data. At surface level the following variables are needed with hourly resolution: wind speed, wind direction, temperature, cloud cover, ceiling height, surface pressure, relative humidity and precipitation rate. The upper air data, needed at least twice daily, must contain for each vertical level: wind speed, wind direction, temperature, pressure and height.
The output of the CALMET model is directly interfaced with dispersion models such as CALPUFF (Lagrangian puff model), CALGRID[6] (Eulerian photochemical model) and LAPMOD[7] (Lagrangian particle model).

[5] Scire, J.S., F.R. Robe, M.E. Fernau and R.J. Yamartino, 2000: A user's guide for the CALMET meteorological model (Version 5). Earth Tech. Inc., Concord, MA.
[6] Scire J.S., Yamartino R.J., Carmichael G., Chang Y. (1996): A User's Guide for the CALGRID Meteorological Model (version 1.6b) – Earth Tech Inc., Concord, MA, United States, July 1996.
[7] Bellasio, R., Bianconi, R., Mosca, S., and Zannetti, P. (2018) Incorporation of Numerical Plume Rise Algorithms in the Lagrangian Particle Model LAPMOD and Validation against the Indianapolis and Kincaid Datasets. Atmosphere, 9(10), 404.

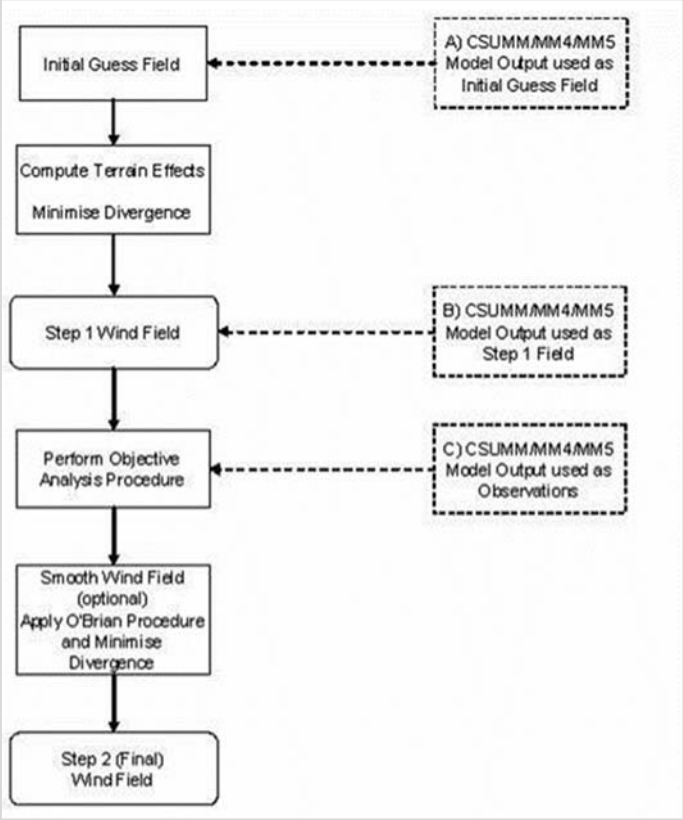

Figure 3. Flow diagram of the diagnostic meteorological model CALMET.

6.3 CALPUFF

CALPUFF[8] is a multi-species non-steady-state puff dispersion model that simulates the effects of time and space varying meteorological conditions on pollutant transport, transformation, and removal. CALPUFF is intended for use on scales from tens of meters from a source to hundreds of kilometres. It includes algorithms for near-field effects such as stack tip downwash, building downwash, transitional buoyant and momentum plume rise, rain cap effects, partial plume penetration, sub grid scale terrain and coastal interactions effects, and terrain impingement as well as longer range effects such as pollutant removal due to wet scavenging and dry deposition, chemical transformation, vertical wind shear effects, overwater transport, plume fumigation, and visibility effects of particulate matter concentrations.

CALPUFF is appropriate for long range transport of emissions from point, volume, area, and line sources. The meteorological input data should be fully characterized with time-and-space-varying three-dimensional wind and meteorological conditions using CALMET. CALPUFF may also be used on a case-by-case basis when the model is more appropriate for the specific application. The purpose of choosing a modelling system like CALPUFF is to fully treat stagnation, wind reversals, and time and space variations of meteorological conditions on transport and dispersion.

[8] Scire, J.S., D.G. Strimaitis and R.J. Yamartino, 2000: A user's guide for the CALPUFF dispersion model (Version 5). Earth Tech. Inc., Concord, MA.

Beside the 3D meteorological fields developed by the CALMET diagnostic meteorological model, CALPUFF can use single station meteorological data stored in format used by other dispersion models (ISC3ST, AUSPLUME, CTDMPLUS). However, single station meteorological files do not allow CALPUFF to take advantage of its capabilities to treat spatially varying meteorological fields. CALPUFF produces files of hourly concentrations of ambient concentrations for each modelled species, wet deposition fluxes, dry deposition fluxes, and for visibility applications, extinction coefficients. The process and information flow needed to carry out the air dispersion study is represented in Figure 4.

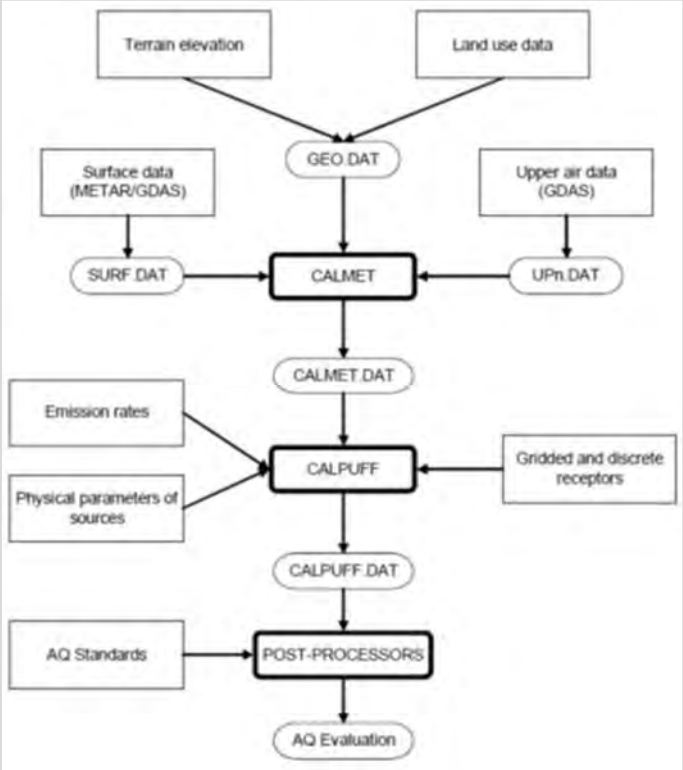

Figure 4. Flow diagram of the CALPUFF modelling system.

7. METEOROLOGICAL FIELDS FOR YEAR 2014

Meteorological data of year 2014 have been selected for the analysis since the same year had been taken as reference in the ERD Air Quality Impact Assessment[9] as well as in the "Study Of The Cumulative Impacts Of Air Emissions In The Murujuga Airshed" developed in 2022 for DWER. This year had been chosen for air quality modelling developed recently in the Murujuga area in light of its meteorology that is typical of recent years and was not an extreme.

[9] Air Quality Impact Assessment. Perdaman Urea Project. Revision 7. March 16, 2020. Jacobs Group (Australia) Pty Limited.

7.1 WRF

The CALMET simulation has been performed using the output of the WRF model as initial guess. WRF has been initialized by means of the NCEP (National Centers for Environmental Prediction) FNL (Final) Operational Global Analysis data[10] on 1-degree by 1-degree grids prepared operationally every six hours. A nesting with 3 grid levels has been used with a nesting factor equal to 3: grid size of 27 km for the outer domain, 9 km for the central domain, and 3 km for the inner domain (whose output has been used to feed CALMET). The modelling domains of WRF are shown in Figure 5. The D03 domain (i.e., the inner one) is shown by a red square whose size is about 200×200 km^2.

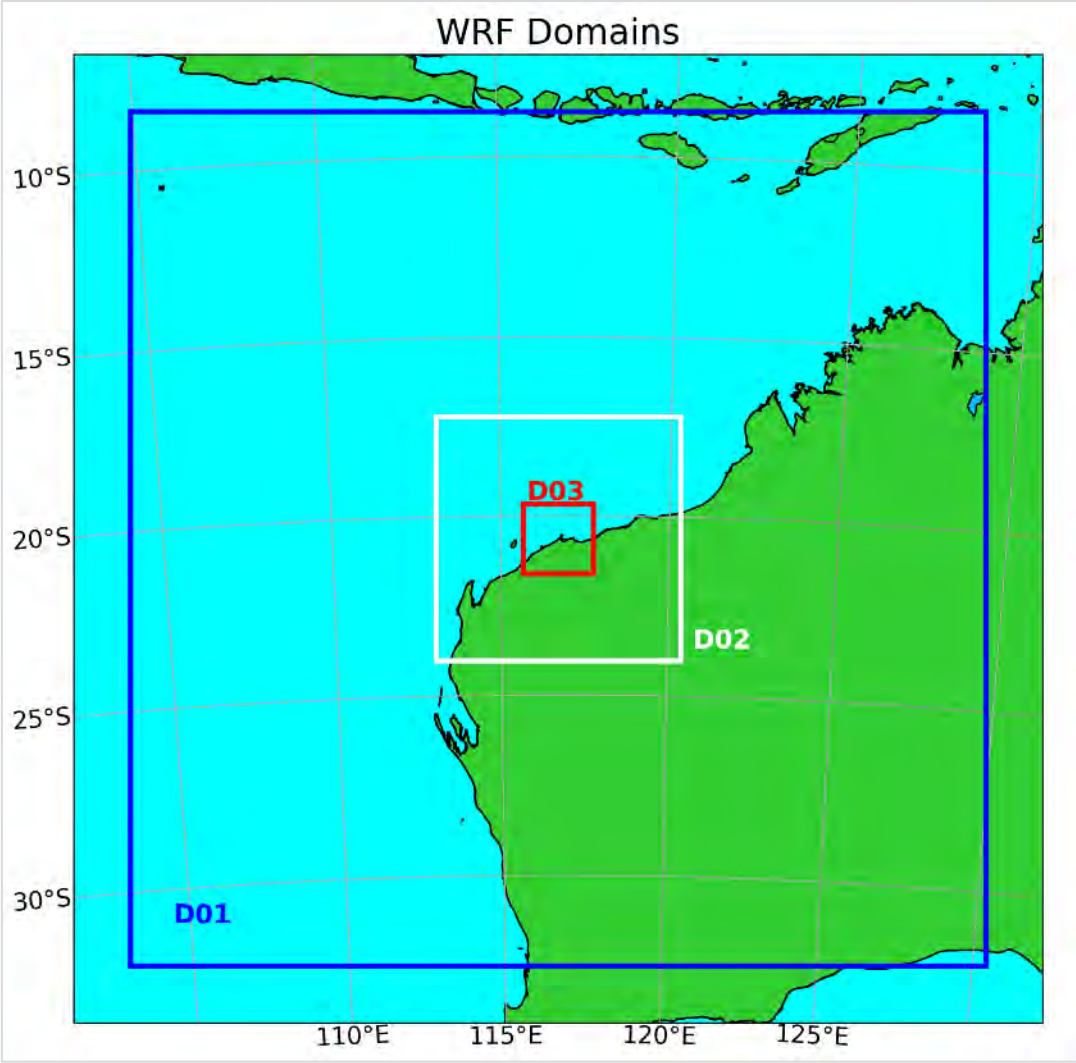

Figure 5. WRF modelling domains.

[10] National Centers for Environmental Prediction/National Weather Service/NOAA/U.S. Department of Commerce (2000), NCEP FNL Operational Model Global Tropospheric Analyses, continuing from July 1999, https://doi.org/10.5065/D6M043C6, Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory, Boulder, Colo. (Updated daily.)

7.2 GEOPHYSICAL DATA

The simulation domain of the CALMET diagnostic meteorological model is represented in Figure 6 by means of a green square (the red circle represents the plant position). The UTM 50K coordinates of the lower left corner of the domain are E=436000 m and N=7678700 m. The domain size is 80×80 km^2 and the horizontal grid resolution is 0.5 km. Along the vertical direction twelve levels have been used, up to a height of 4000 m. The time period simulated is the whole year 2014.
The average terrain height over the 0.5×0.5 km^2 grid cells has been determined starting from the Shuttle Radar Topography Mission data (SRTM) with an original resolution of 3 arc second (about 90 m) with the TERREL processor. The result of this processing is shown in Figure 7.
The MODIS Land Cover data with a resolution of about 500 m have been used for preparing the land use information through the CTGPROC processor. The final result is shown in Figure 8.

Figure 6. Simulation domain of the CALMET meteorological model.

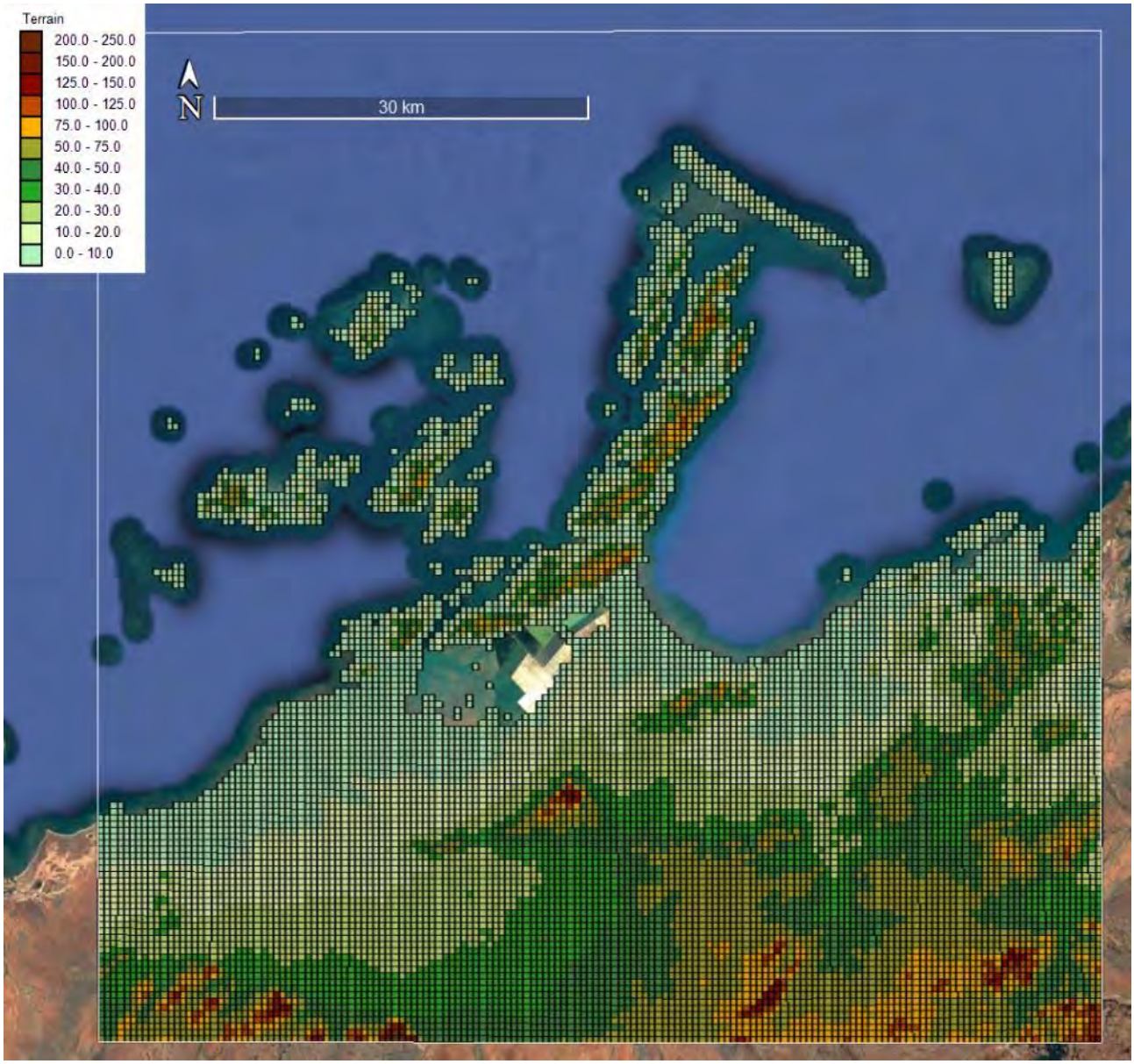

Figure 7. Average terrain elevation over the 500 m CALMET grid cells.

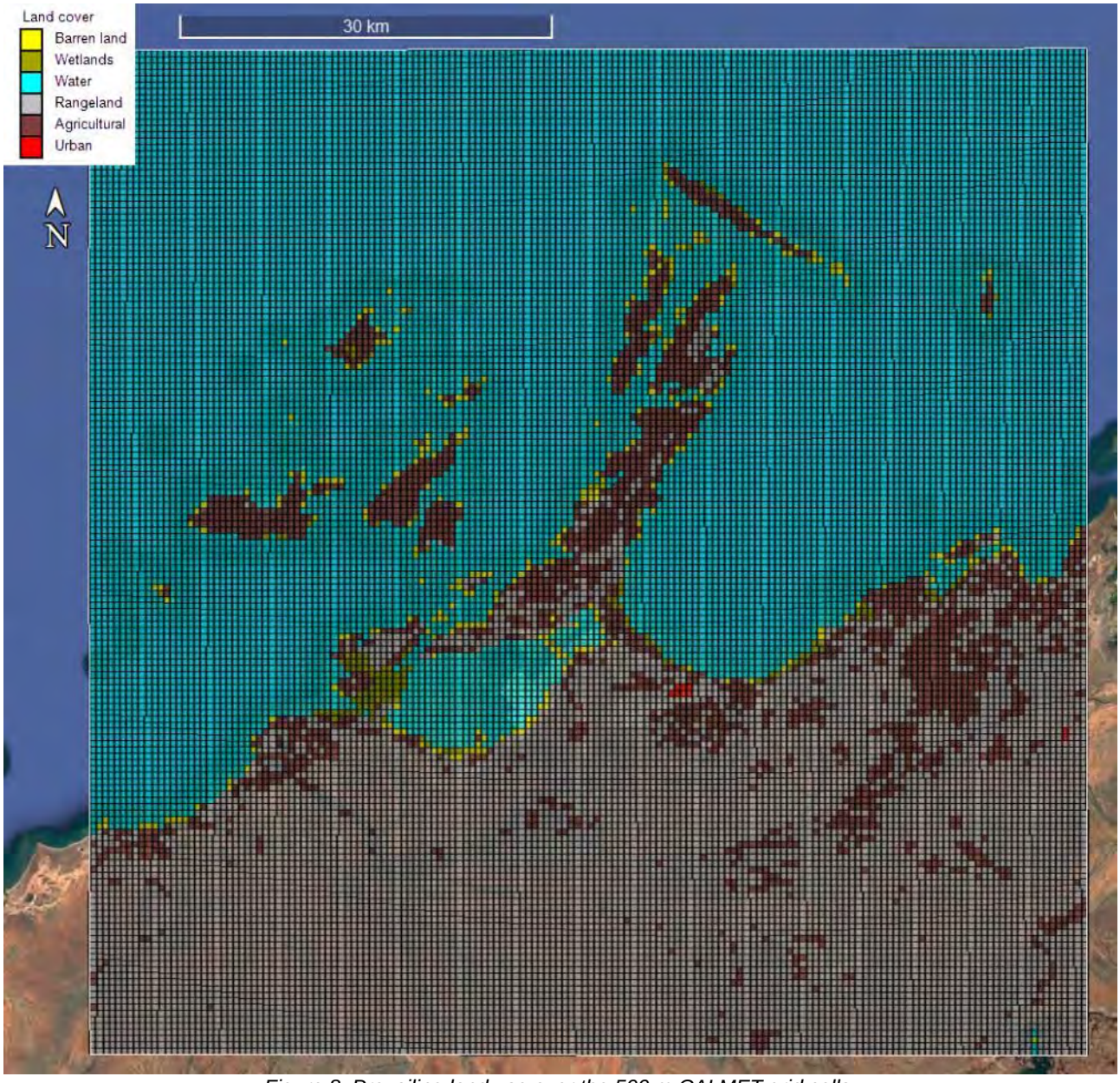

Figure 8. Prevailing land use over the 500 m CALMET grid cells.

7.3 CALMET RESULTS AT THE KARRATHA AIRPORT

At the end of the meteorological simulations, in order to evaluate the results, the output data have been extracted from the CALMET grid cells containing the Karratha airport and the plant.
The Karratha airport is located few kilometres NW from the city, with a runway aligned east to west. The Integrated Surface Data (ISD) Lite meteorological data measured at the airport during the year

2014 have been downloaded[11] and used to prepare the wind rose[12]. Wind roses were also prepared from the CALMET data extracted from point E = 475704 m, N = 7709191 m (UTM zone 50K), which is representative for the airport. The observed and modelled wind roses are represented in Figure 10. The plots show a satisfactory agreement between measurements and model results: the prevailing winds are always from the western sector (explaining the runway direction), and secondary features such as the small cluster of winds blowing from NE are also reproduced. Some differences between the observed and the modelled wind roses may be due to the fact that, while the modelled wind rose has been obtained from all the 8760 hours of year 2014, the observed wind rose has been created from less than 4000 data, because the other ones are not available.

Figure 9. Position of the airport with respect to Karratha.

[11] https://www1.ncdc.noaa.gov/pub/data/noaa/isd-lite/
[12] The WindRose PRO3 software has been used (https://www.enviroware.com/portfolio/windrose-pro3/)

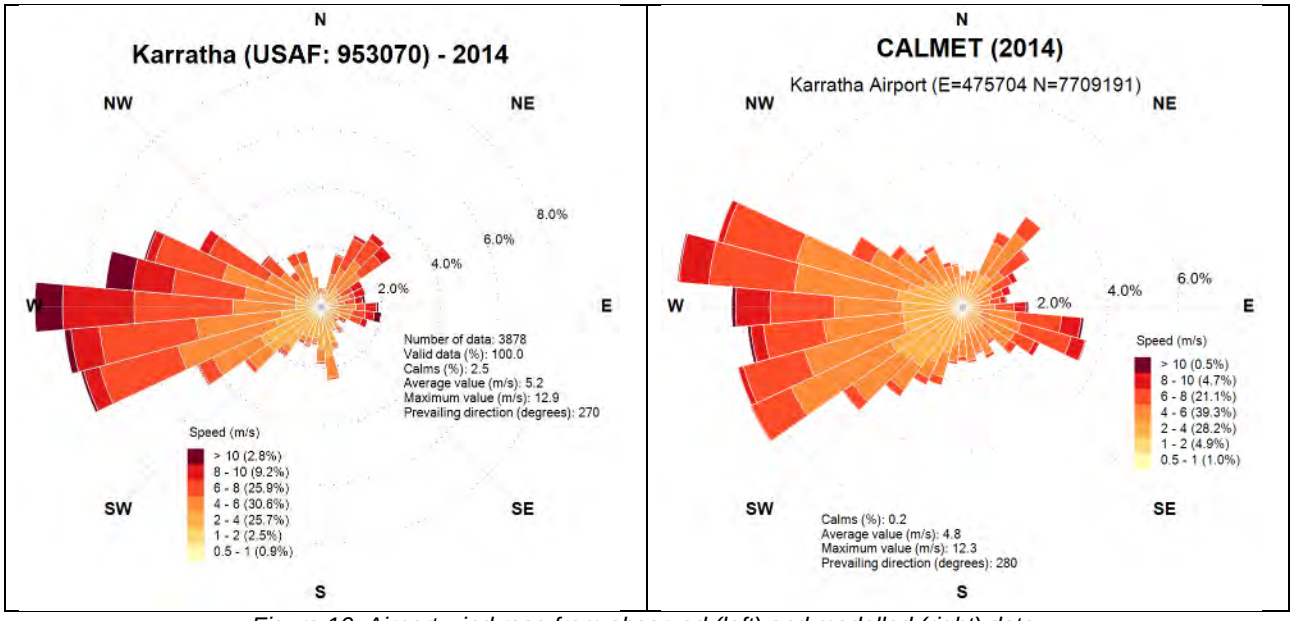

Figure 10. Airport wind rose from observed (left) and modelled (right) data.

7.4 CALMET RESULTS AT THE PLANT

The data extracted from the output of CALMET for a point over the plant (E = 476270 m, N = 7718834 m, UTM zone 50K) at a height of 10 m above ground level have been used to perform the analysis described in this paragraph.

7.4.1 Wind roses

The wind rose plot for the whole year 2014 is shown in Figure 11; it shows prevailing wind blowing from west, and frequent winds also from ESE. Calm conditions (i.e., events characterized by wind speed lower than 0.5 m/s) are a small fraction of the hours (0.3%). The annual average wind speed is 5.0 m/s.

The monthly wind roses for the plant are shown in Figure 12. They show that from January to March, and from October to December, the winds blow almost exclusively from west. On the contrary, in June, July and August they blow almost exclusively from east. The strongest winds blow in July.

The hourly wind roses are shown in Figure 13 and Figure 14. They show how wind speed and wind direction are distributed, on average, during the hours of the day.

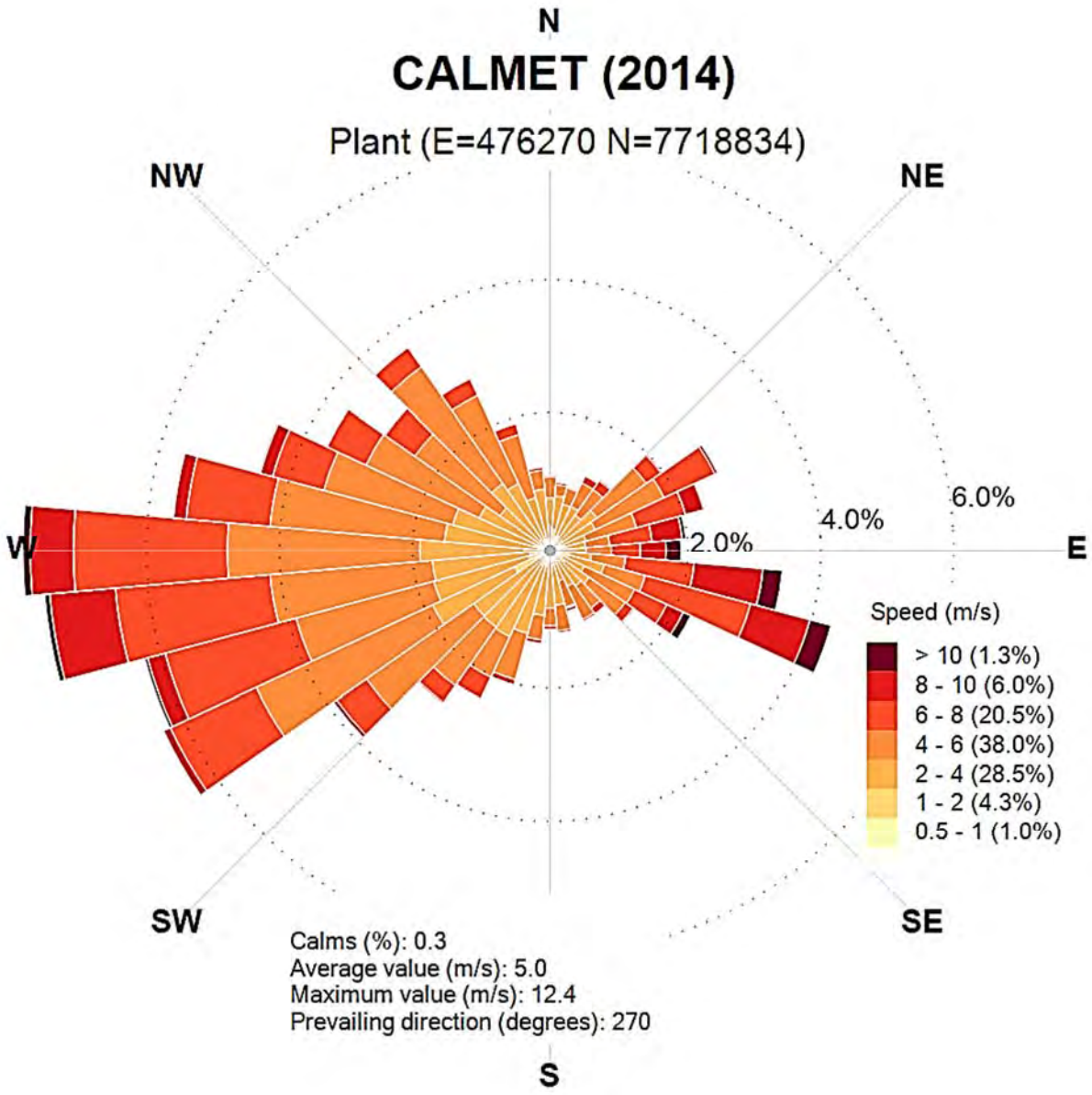

Figure 11. Wind rose of year 2014 from CALMET data over the plant.

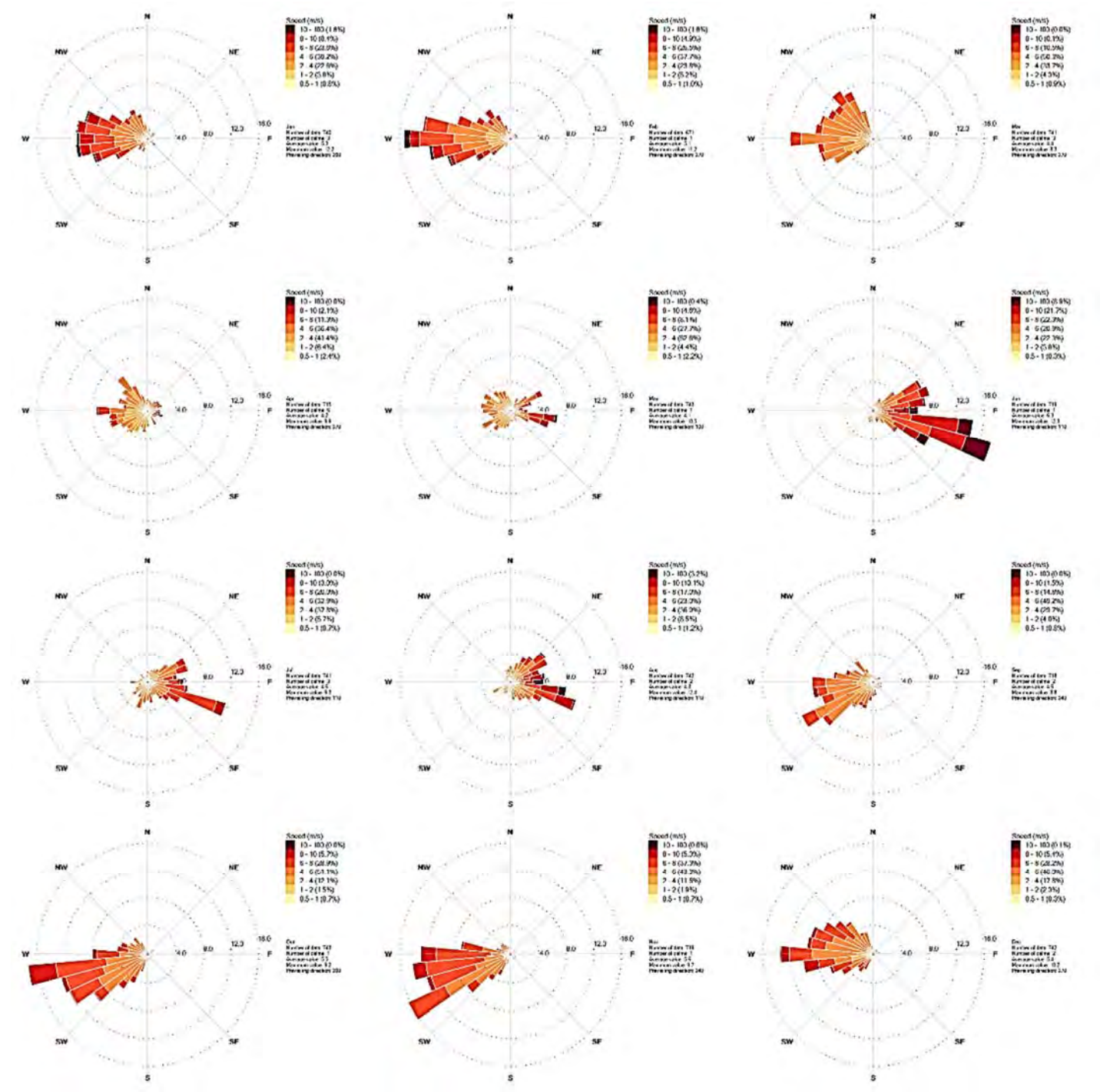

Figure 12. Monthly wind roses of year 2014 from CALMET data over the plant.

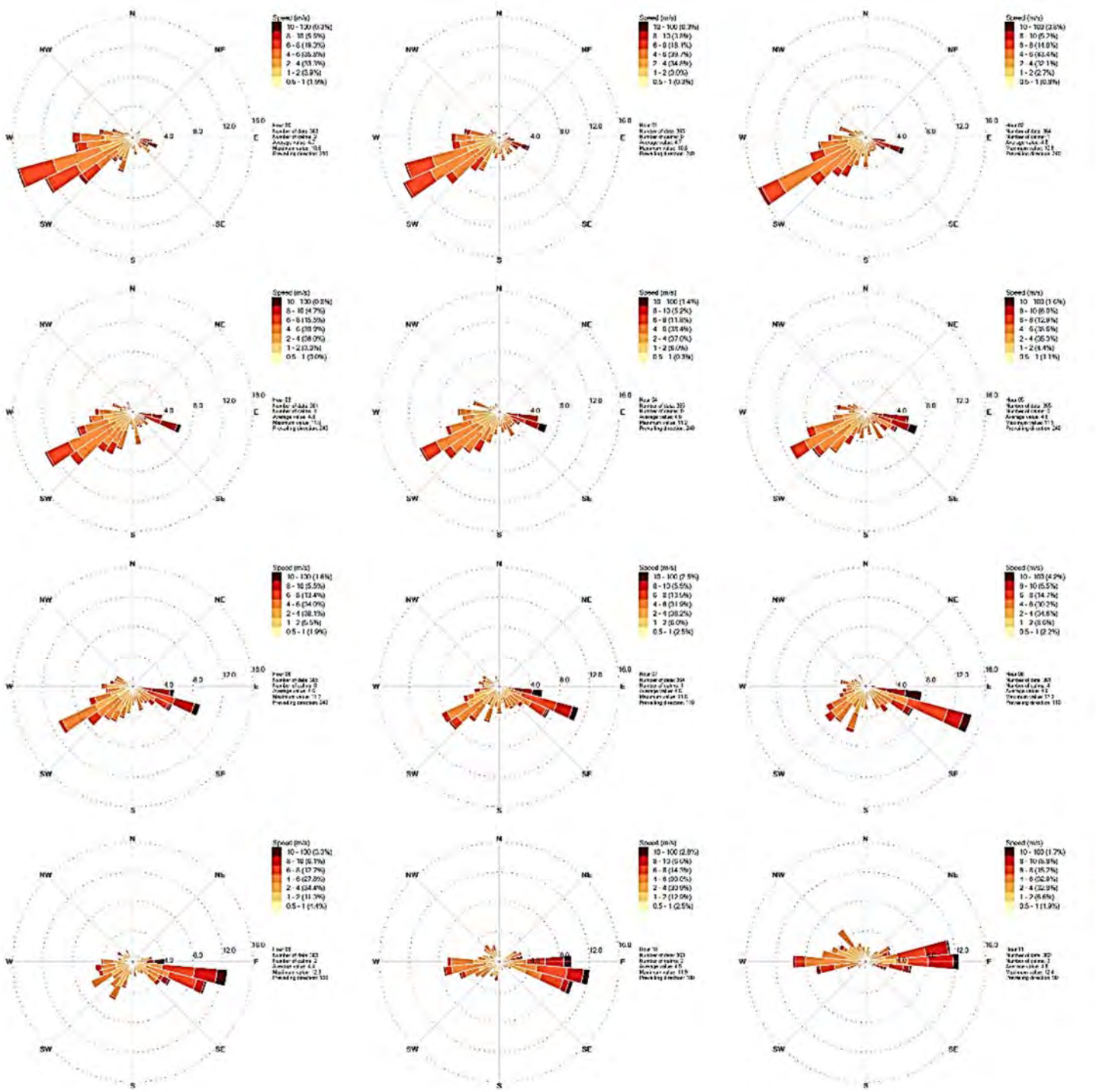

Figure 13. Hourly (00-11) wind roses of year 2014 from CALMET data over the plant.

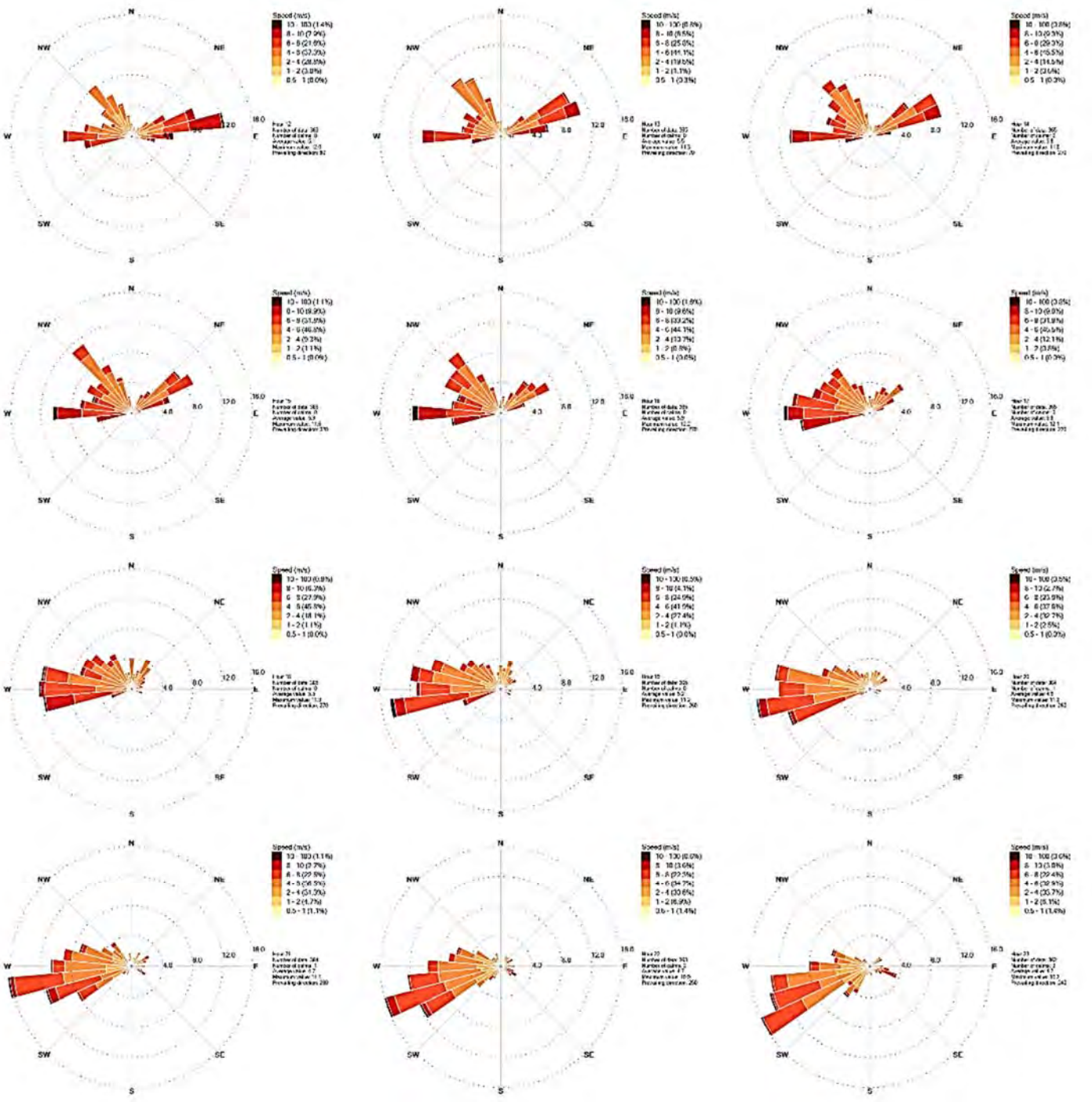

Figure 14. Hourly (12-23) wind roses of year 2014 from CALMET data over the plant.

7.4.2 **Precipitation**

The monthly precipitation for year 2014 obtained from the CALMET data over the plant is shown in Figure 15. The maximum value is 77 mm in May, while in September, October and November there is no precipitation. The total precipitation in 2014 is 109 mm.

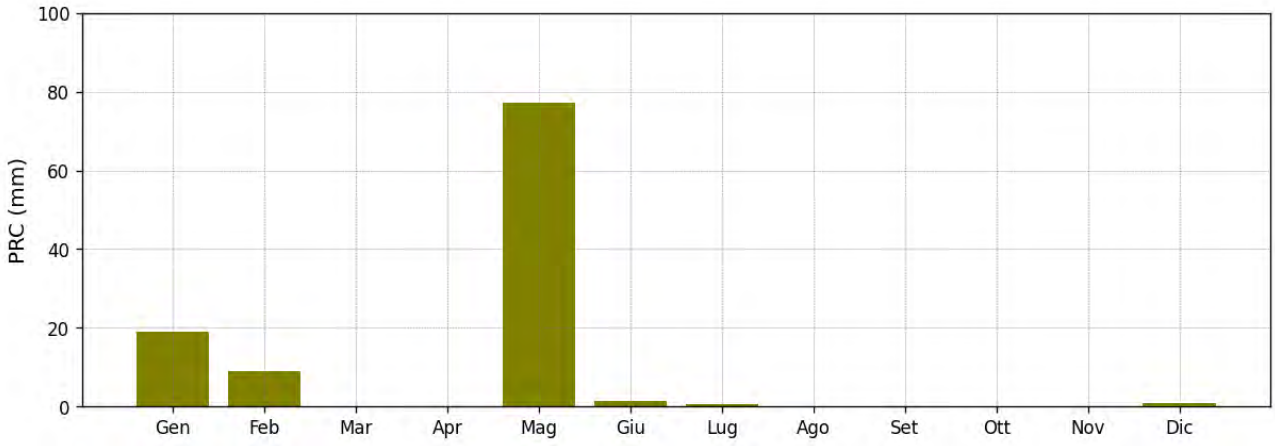

Figure 15. Monthly precipitation of year 2014 from CALMET data over the plant.

7.4.3 **Temperature**

The monthly distribution of the temperature values extracted from CALMET over the plant is shown in Figure 16 through a “box and whiskers” plot. In such a plot the vertical rectangle (box) extends from the first to the third quartile of data (i.e., from the 25th percentile to the 75th percentile of data), the horizontal segment within the box represents the median value, while the triangle represents the average. The two horizontal segments (whiskers) at the extremes of each vertical bar represent the minimum and the maximum values.
The average annual temperature is 26.5 °C. The minimum hourly value is 12.4 °C (July) while the maximum hourly value is 41.0 °C (January).

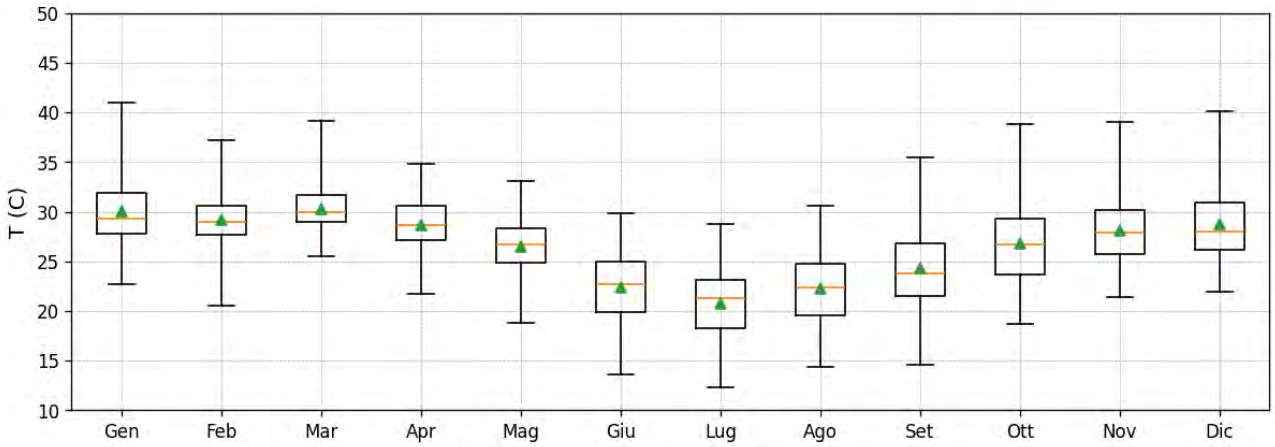

Figure 16. Monthly temperature distribution of year 2014 from CALMET data over the plant.

7.4.4 **Mixing height**

The monthly distribution of the mixing height values extracted from CALMET over the plant is shown in Figure 17 through a “box and whiskers” plot. As expected, the average values are greater during the hot months than during the cold months. June is an exception because it is characterised by high wind speed values (Figure 12), then by high levels of mechanical turbulence.
The typical day of the mixing height values is shown in Figure 18. The minimum values, of the order of 400 m, are calculated for the night hours, while during the day the values increase with the solar radiation (convective turbulence).

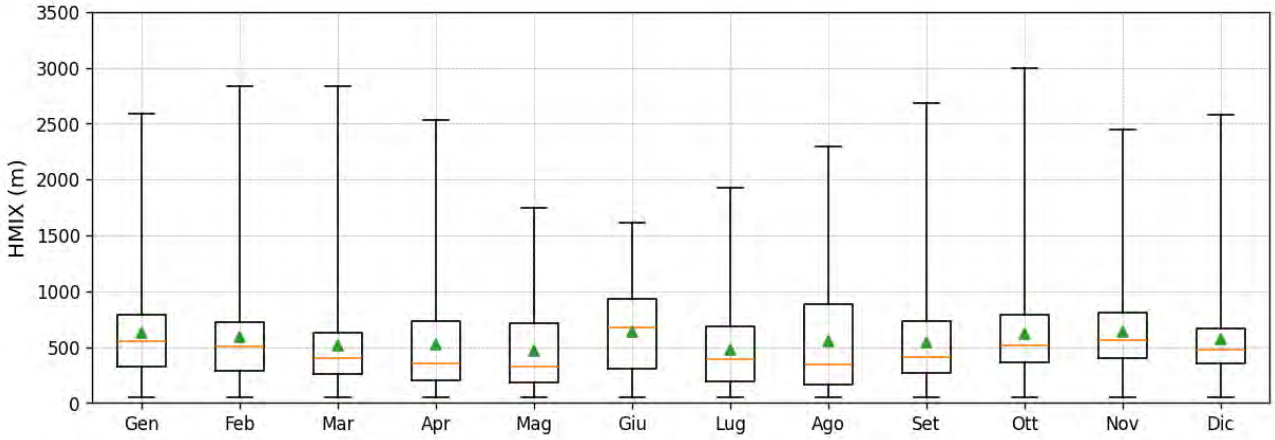

Figure 17. Monthly mixing height distribution of year 2014 from CALMET data over the plant.

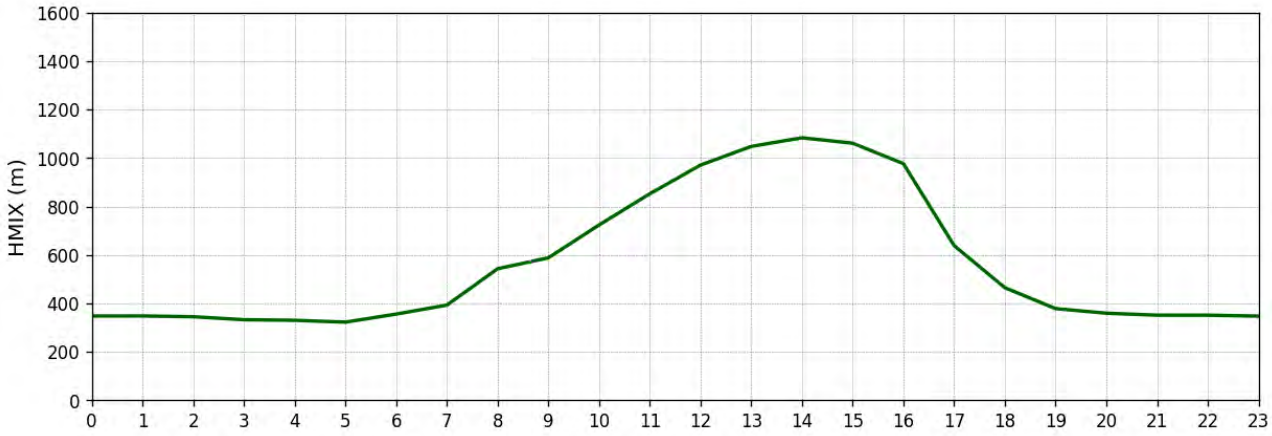

Figure 18. Typical day of the mixing height for year 2014 over the plant.

7.4.5 **Pasquill Gifford stability classes**

The distribution of the Pasquill Gifford stability classes is shown in Figure 19. The most probable class is D (about 40% of the hours), corresponding to neutral conditions where the turbulence is of

mechanical origin (wind). On the contrary, the less probable class is A (less than 1% of the hours), which corresponds to very unstable conditions with high solar radiation and very low wind speed.

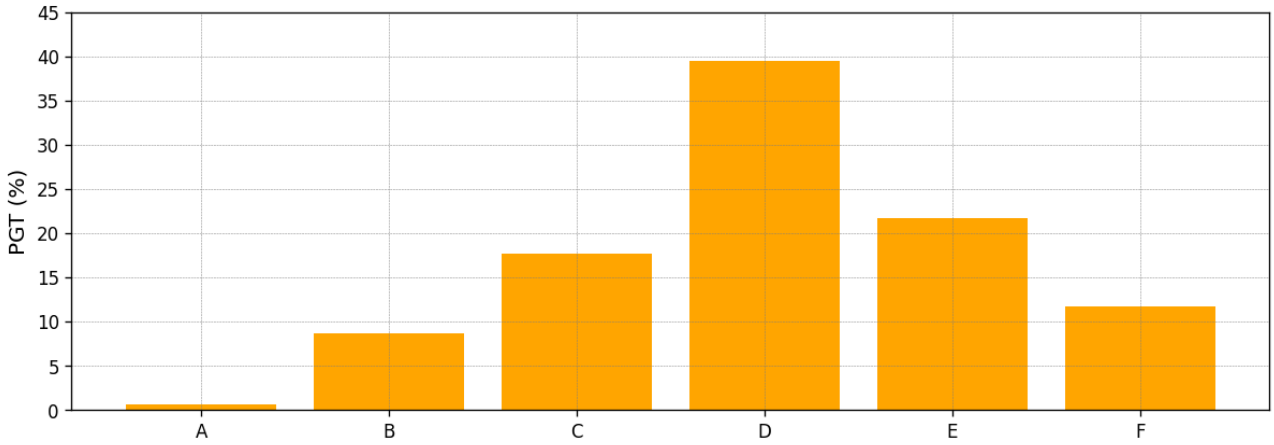

Figure 19. Distribution of the Pasquill Gifford stability classes for year 2014 over the plant.

8. EMISSION SCENARIOS

The flare system is designed to ensure safe disposal of various process streams to atmosphere during start-up and (planned or emergency) shutdown. It consists of 7 flares (2 of which are in Ammonia plant, 1 in Ammonia storage area and 2 are foreseen respectively for Urea plant train 1 and train 2). The description of the seven flares, their MGA 94 coordinates, their height above the ground (i.e., the difference between top of the stack and ground elevation at stack base AHD), and the terrain height at their bases are summarised in Table 3.

Table 3. Flares geometrical parameters.

ID	Description	E (m)	N (m)	Terrain AHD (m)	Flare Height (m)
3420-PK-102	Syngas Flare	476280	7719159	8.0	92
3410-PK-101	Ammonia Flare	476280	7719163	8.0	92
3430-PK-103	Ammonia Storage Flare	476248	7719090	8.0	30
2610-PK-112	Primary Urea Flare – Train 1	476305	7719005	6.5	66
2610-PK-113	Secondary Urea Flare – Train 1	476301	7719005	6.5	66
2710-PK-112	Primary Urea Flare - Train 2	476305	7718893	6.5	66
2710-PK-113	Secondary Urea Flare – Train 2	476301	7718893	6.5	66

Emission data for flares derive from the US EPA methodology[13] that allow to determine the effective source parameters. The main points of the methodology are summarized in the following:

- 55% of the heat generated is lost for radiation, therefore 45% is available as sensible heat;
- the effective stack diameter is calculated starting from the sensible heat flux;
- the effective stack height is calculated starting from the gross heat released;

13 US-EPA (1995) SCREEN3 Model User's guide. EPA-454/B-95-004. https://gaftp.epa.gov/Air/aqmg/SCRAM/models/screening/screen3/screen3d.pdf

- the exit velocity is assumed equal to 20 m/s;
- the exit temperature is assumed equal to 1000 °C (1273 K).

Then $Q_n = 0.45 \times Q$, where Q_n is the net heat release from the flare (cal/s) and Q is the gross heat release (cal/s). The equivalent diameter is calculated as $D_E = 9.88 \times 10^{-4} (Q_n)^{0.5}$, and the equivalent stack height is calculated as $H_E = H_S + (4.56 \times 10^{-3} \times Q^{0.478})$, where H_S is the physical stack height.

The emission rates of SO_2 are derived from sulphur content of input stream (stochiometric approach). The emission rates of NO_X, CO, and PM10 have been calculated applying the emission factors of 0.068 lb/10^6BTU (for NO_X), of 0.31 lb/10^6 BTU (for CO), and 0.00219 kg PM10/kg flare gas (for PM10), as indicated in the US-EPA AP-42, Compilation of Air Pollutant Emission Factors (13.5 Industrial Flares[14]). Also, when ammonia (NH_3) is part of the stream, it is assumed that conservatively 5% of its moles are burnt and transformed into NO_X; this amount is added to the one obtained with the emission factor.

A total of 12 flaring scenarios have been analysed: 7 single flaring scenarios, corresponding to the most significative scenarios identified as critical by DWER during Work Approval review, and in addition have been identified and analysed 5 plausible simultaneous flaring scenarios.
Regarding the simultaneous scenarios, a process analysis identified 7 plausible simultaneity scenarios that, although highly unlikely, can occur. This led to the inclusion of 5 scenarios in the dispersion analysis, as 2 scenarios were excluded due to their similarities with already considered scenarios that have greater impacts in terms of emissions.

Table 4 and Table 5 summarize the scenarios selected and considered in the present analysis. As described in the two tables, the release duration should never exceed one day, and in most cases, it does not exceed one hour. However, since it is not possible to know when the release will happen, all the hours of the year have been simulated. This is a conservative approach because the modelling calculates - over all the grids - concentration levels considering all the hours of the year, and relevant meteo condition, and provide for all cell of the grid the maximum level. In this way it provides a vision of what the maximum concentration would be at each point on the map if the release occurred in the hour with the worst weather condition for that specific position.

The stream composition of the selected flaring scenarios is summarised in Table 6. Streams A10 and U4 are involved only in some simultaneous scenarios, while all the other streams are involved in the single-flare scenarios and in some simultaneous scenarios.
Starting from the composition, the heat released by each stream has been determined, then the emission parameters have been calculated for the different scenarios as described before. The emission parameters are summarised in Table 7. The single scenarios are A1, A4, A8, U6, U8, U9 and S2. The simultaneous scenarios are A (A1 and S2), B (A10 and A4), Ca (U4 and A8), D (U6 and U4) and Ea (U4 and U9).

[14] https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-fifth-edition-volume-i-chapter-13-miscellaneous-0

Table 4. Selected single-flaring scenarios.

Scenario	Description	Fluid	Max amount (kg/h)	Destination	Frequency	Duration
A1	FE Start Up (Vent d/s V-311)	Hydrogen	65928	Syngas flare	0-5 times per year	< 1 day
A4	Trip of N2 wash unit	Process gas	324720	Syngas flare	0-5 times per year	< 1 day
A8	2500-K-441 Discharge	Ammonia	123416	Ammonia flare	1 time per 10 years	< 1 hour
U6	H.P. section vent from 2610-V-101 through 2610-PV-1021B fully open). H.P. synthesis loop instability during start-up.	HP vent	30035	Secondary Urea Flare Train 1(*)	1 time per 10 years	10 min
U8	M.P. section instability during start-up (2610-C-101 draining to 2610-V-106) PCT/2610-C-102 top diverted to flare during start-up / long shut-down	LP + PCT vent	10127	Secondary Urea Flare Train 1(*)	0-2 times per year	30 min
U9	LP section vent from 2610-C-104 through 2610-PV-1033 partially open PCT during process upset (2610-C-102 top diverted to flare)	LP + PCT vent	13118	Secondary Urea Flare Train 1(*)	0-2 times per year	1 hour
S2	Ammonia BOG compressor blocked outlet	Ammonia	2620	Ammonia Storage Flare	1 time per 10 years	< 1 hour

(*) Scenarios U6, U8 and U9 refer to the Secondary Urea Flare of Train 1 (2610-PK-113) but these scenarios are equally valid for assessing dispersion of analogous relief scenario from Secondary Urea Flare of Train 2 (2710-PK-113)

Table 5. Selected simultaneous flaring scenarios.

Scenario	Description	Combined events	Max amount (kg/h)	Destination	Frequency	Duration
A	Blocked outlet @ ammonia BOG compressor (storage tank unit) during ammonia plant front-end startup phase (opening of 1300-PV-3501)	FE Start Up (Vent d/s V-311) – **A1**	65928	Syngas flare	0-5 times per year	< 1 day
		Ammonia BOG compressor blocked outlet – **S2**	2620	Ammonia Storage Flare	1 time per 10 years	< 1 hour
B	Trip of CO2 Removal gas and syngas compressor trip automatically activated in cascade	2500-K-431 Syngas compressor trip – **A10**	220000	Ammonia flare	0-5 times per year	< 1 min
		Trip of CO2 Removal gas – **A4**	324720	Syngas flare	0-5 times per year	< 1 day
Ca	Blocked outlet @ ammonia refrigeration compressor 2500-k-441 during urea granulation washing @ one of the two urea trains	Granulation unit in shut-down – **U4**	2431	Primary Urea Flare – Train 1 [or Train 2]	Once every 30 days	8 hours
		2500-K-441 Discharge blocked outlet – **A8**	123416	Ammonia flare	1 time per 10 years	< 1 hour
Cb (*)	Blocked outlet @ ammonia BOG compressor (storage tank unit) during urea granulation washing @ one of the two urea trains.	Granulation unit in shut-down – **U4**	2431	Primary Urea Flare – Train 1 [or Train 2]	Once every 30 days	8 hours
		Ammonia BOG compressor blocked outlet – **S2**	2620	Ammonia Storage Flare	1 time per 10 years	< 1 hour
D	H.P. synthesis loop instability during start-up when one of the two granulation unit is in shutdown	H.P. section vent from V-101 through – **U6**	30035	Secondary Urea Flare – Train 1 [or Train 2]	1 time per 10 years	10 min
		Granulation unit in shut-down – **U4**	2431	Primary Urea Flare – Train 1 [or Train 2]	Once every 30 days	8 hours
Ea	PCT during process upset (2610-C-102 top diverted to flare) when one of the two granulation unit is in shutdown	Granulation unit in shut-down – **U4**	2431	Primary Urea Flare – Train 1 [or Train 2]	Once every 30 days	8 hours
		LP section vent from 2610-C-104 through 2610-PV-1033 partially open PCT during process upset (2610-C-102 top diverted to flare) – **U9**	13118	Secondary Urea Flare – Train 2 [or Train 1]	0-2 times per year	1 hour
Eb (**)	M.P. section instability during start-up when one of the two granulation unit is in shutdown.	Granulation unit in shut-down – **U4**	2431	Primary Urea Flare – Train 1 [or Train 2]	Once every 30 days	8 hours
		M.P. sect. ion instability during start-up (2610-C-101 draining to 2610-V-106) PCT/2610-C-102 top diverted to flare during start-up / long shut-down – **U8**	10127	Secondary Urea Flare Train 1	0-2 times per year	30 minutes

(*) This is a plausible scenario but its entity is significantly lower than scenario Ca which is decidedly more burdensome in terms of emissions.
(**) This is a plausible scenario but its entity is significantly lower than scenario Ea which is decidedly more burdensome in terms of emissions.

Table 6. Stream composition (kg/h) of the selected flaring scenarios.

Composition	A1	A4	A8	U6	U8	U9	S2	A10	U4
H_2	32934.42	26897.94	0.00	0.00	0.00	0.00	0.00	5156.05	7.12
CO_2	15.47	196518.18	347.55	917.62	281.91	1617.13	9.61	0.00	29.26
CO	18261.57	14949.82	0.00	6.35	0.00	0.00	0.00	0.00	6.79
N_2	9845.54	8055.70	294.96	1132.36	37.68	40.83	8.16	214837.01	1229.74
NH_3	0.00	0.00	123424.12	25733.95	5790.21	6082.91	2620.22	0.00	8.25
CH4	4144.22	3395.45	3800.74	1157.92	485.54	526.11	105.13	0.00	321.37
C_2H_6	0.00	0.00	213.72	65.04	27.30	29.58	5.91	0.00	17.99
C_3H_8	0.00	0.00	34.82	10.60	4.45	4.82	0.96	0.00	2.93
S - Sulphur	0.00	0.00	0.08	0.03	0.01	0.01	0.00	0.00	0.01
Ar - Argon	631.80	551.41	0.00	19.39	0.00	0.00	0.00	6.95	24.54
O_2 - Oxygen	0.00	0.00	0.00	181.23	0.00	0.00	0.00	0.00	202.39
H_2O - Water	94.97	74351.51	0.00	810.42	3500.00	4817.05	0.00	0.00	580.65
Total (kg/h)	**65928.00**	**324720.00**	**128116.00**	**30034.90**	**10127.10**	**13118.44**	**2750.00**	**220000.00**	**2431.04**

Table 7. Emission parameters for the selected flaring scenarios.

Scenario	Gross heat release Q (cal/s)	Height equivalent H_E (m)	Diameter equivalent D_E (m)	NO_X (g/s)	CO (g/s)	PM10 (g/s)	SO_2 (g/s)
A1	2.88E+08	142.4	11.3	35.28	160.81	40.11	-
A4	2.35E+08	137.8	10.2	28.82	131.37	197.54	-
A8	1.66E+08	130.7	8.5	4650.47	92.55	77.94	0.0468
U6	3.59E+07	84.6	4.0	969.79	20.02	18.28	0.0142
U8	8.86E+06	75.5	2.0	218.31	4.95	6.17	0.0060
U9	9.37E+06	75.8	2.0	229.35	5.23	7.99	0.0065
S2	3.61E+06	36.2	1.3	98.74	2.02	1.68	0.0013
A10	4.10E+07	111.87	4.2	5.03	22.91	133.84	-
U4	1.20E+06	69.68	0.7	0.46	0.68	1.48	0.0039

9. FLARING AIR QUALITY ANALYSIS

9.1 CALPUFF INPUT DATA

The whole meteorological domain has been used as computational domain of the CALPUFF dispersion model, in order to be sure that the highest concentrations will fall inside it because of the high values of mean wind speed. Then, both the computational domain and the sampling domain

have been defined as a square of 80×80 km^2. The size of the CALPUFF grid is 500 m. The computational domain is the area within which CALPUFF moves the puffs released by each source, while the sampling domain is the area within which the output concentrations are calculated.

The options required by the NSW EPA[15] have been activated in CALPUFF. Specifically:

- Default wind speed profile: ISC Rural (PLX0 set to rural coefficient for each stability class)
- Transitional plume rise (MTRANS=1)
- Stack tip downwash (MTIP=1)
- Partial plume penetration (MPARTL=1)
- Dispersion curves: dispersion coefficients from internally calculated sigma v, sigma w using micrometeorological variables (MDISP=2)
- No adjustment of dispersion curves for roughness (MROUGH=0)
- Terrain: Partial plume adjustment (MCTADJ=3)

Moreover, the dry and wet depositions algorithms have not been activated in order to maximize the atmospheric concentrations of the pollutants.

At the end of the simulations, the CALPOST processor has been applied to extract the statistics of interest: maximum 1-hour concentration for NO_2, CO and SO_2, and maximum 24-hour concentration for PM10.

It is observed that the flares coordinates are expressed with datum GDA94 (Geocentric Datum of Australia 1994) and projection MGA (Map Grid of Australia) within zone 50 (MGA zone 50), as reported in Table 3. This coordinate system is described by the EPSG code 28350. CALPUFF and CALMET work with datum WGS84 and UTM projection (Universal Transverse Mercator). This coordinate system, for the UTM zone 50S, is described by the EPSG code 32750. The MGA50 flares coordinates have been transformed into UTM50S coordinates before performing the simulations. The difference between the coordinates of the same point expressed in the two projections is negligible (i.e., of the order of a cm or less) within the area of interest. All the coordinates reported in the following tables are UTM50S.

9.2 SENSITIVE RECEPTORS

Beside the Cartesian grid described in paragraph 9.1, a total of 17 sensitive (discrete) receptors have been considered. Sensitive receptors have been defined considering locations that may be of interest for different reasons (e.g., high population density, presence of fragile people, historical relics that may be damaged by pollutants). The UTM coordinates (zone 50S) of these discrete receptors are reported in Table 8.
Receptors from R1 to R10 reflect those considered in the ERD Air Quality Impact Assessment[9], while the remaining 7 receptors (R11-R17) have been specifically considered with the aim to analyse other potentially impacted sensitive locations at a greater distance from the Project area. The position of the receptors is illustrated in Figure 20. Receptors R15, R16 and R17 are about at 40 km from the plant (represented with a white polygon next to receptor R8) close to the eastern boundary of the

[15] Paragraph 6.5 of https://www.epa.nsw.gov.au/~/media/EPA/Corporate%20Site/resources/epa/approved-methods-for-modelling-and-assessment-of-air-pollutants-in-NSW-160666.ashx

domain. They have been considered because sometimes flares may impact areas also very far from their locations. All the receptors are considered at ground level.

Table 8. UTM50S Coordinates of the sensitive receptors.

Receptor	E (m)	N (m)	Description
R1	476665	7721038	Woodside Air Quality Monitoring Station (AQMS), Burrup Road
R2	470239	7716142	Woodside AQMS Dampier
R3	484892	7707575	Woodside AQMS Karratha
R4	477964	7718020	Ngajarli (ex-'Deep Gorge')
R5	478928	7718358	Hearson Cove
R6	483354	7730501	Murujuga National Park - central northern extent
R7	476195	7714869	Murujuga National Park - central southern extent
R8	475574	7719459	Representative of MAC office, King Bay
R9	474714	7717782	Standing Stones
R10	479900	7727100	Murujuga Living Knowledge Centre (MLKC)
R11	469946	7715139	Dampier
R12	479477	7706260	Nickol
R13	481869	7706555	Millars Well
R14	483700	7707176	Karratha
R15	514383	7713426	Wickham
R16	514594	7703797	Roebourne
R17	512446	7705431	Cheeditha Community

Figure 20. Positions of the sensitive receptors.

9.3 NO_2 CALCULATION

Nitrogen oxides resulting from the combustion are mainly constituted by nitrogen monoxide (NO) and, with a relatively small amount, by nitrogen dioxide (NO_2). NO present in the plumes gradually mixes with the atmosphere, reacts with ozone (O_3) and other oxidants and, in the end, it oxidizes to NO_2. There are other numerous reactions in the atmosphere regarding NO_X and, during daytime, it is also present the photo-dissociation of NO_2 that, absorbing UV radiation, generates NO.
However, in the early stages of plume dispersion (at distances up to about 10 km and over time intervals of up to about 300 minutes), the main reaction of the NO_X is the oxidation of NO to form NO_2 by O_3 (Karamchandani et al, 1998)[16].
The US-EPA indicates three different levels of approach for the evaluation of the relationship between the concentrations of NO_2 and the ones of NO_X (for the analysis of total dispersion for authorization purposes) identified by the methods Tier 1, Tier 2 and Tier 3, and characterized by decreasing precautionary levels.
In detail:

- Tier 1 assumes the full conversion of emitted NO to NO_2. The calculated concentrations of NO_X are then treated as NO_2 concentrations. This is the more conservative approach of screening.

[16] Karamchandani, P., Koo, A., & Seigneur, C. (1998). Reduced gas-phase kinetic mechanism for atmospheric plume chemistry. Environmental science & technology, 32(11), 1709-1720.

- Tier 2 uses the Ambient Ratio Method (ARM), through the application of a simplified conversion factor equal to 0.8 and derived in an empirically way, to be applied for the concentrations of total nitrogen oxide predicted by the model. The application of a fixed and constant factor still gives a conservative estimate, because it's applied a constant correction factor throughout the domain, regardless of permanence in the atmosphere. The approach thus leads to an overestimation of NO_2 concentration, in particular in the vicinity of the emission source (Podrez, 2015)[17].

- Tier 3 is a specific analysis of the case, by applying appropriate conversion factors derived from the case and that is site specific.

Conservatively, Tier 1 method for NO_X 1-hour average concentration had been considered in the present study, applying therefore a full conversion of the emitted NO_X into NO_2.

[17] Podrez M. (2015) An update to the ambient ratio method for 1-h NO2 air quality standards dispersion modeling. Atmospheric Environment, 103, 163-170.

9.4 SCENARIO A1

The estimated frequency of scenario A1 is 0-5 times per year, and the release duration is less than one day (Table 4). In this scenario SO_2 is not emitted. The stream is mainly composed by hydrogen, and its destination is the syngas flare. The maximum concentrations calculated over the Cartesian receptors are summarised in Table 9, while those estimated at the sensitive receptors are reported in Table 10. All predicted concentrations are below the corresponding reference values.
The GLCs of the pollutants are represented from Figure 21 to Figure 23.

Table 9. Maximum concentrations over the Cartesian receptors. Scenario A1.

Pollutant	Statistics	E (m)	N (m)	Value (µg/m^3)	ERPG-2 (µg/m^3)	Value/ERPG-2 (%)
NO_2	Max 1h	476750	7718450	32.5	28211	0.12
CO	Max 1h	476750	7718450	148.0	400731	0.04
PM10	Max 24h	476750	7718450	2.3	50	4.54
SO_2	Max 1h	-	-	-	7857	-

Table 10. Maximum concentrations at the sensitive receptors. Scenario A1.

Receptor	NO_2 Max 1h (µg/m^3)	CO Max 1h (µg/m^3)	PM10 Max 24h (µg/m^3)	SO_2 Max 1h (µg/m^3)
R1	2.3	10.5	0.3	-
R2	2.8	12.8	0.4	-
R3	2.3	10.5	0.3	-
R4	13.3	60.8	1.7	-
R5	7.6	34.7	1.2	-
R6	1.6	7.3	0.2	-
R7	5.0	22.6	1.0	-
R8	4.3	19.7	0.4	-
R9	6.7	30.3	0.6	-
R10	2.7	12.2	0.2	-
R11	2.4	11.2	0.4	-
R12	2.4	11.0	0.4	-
R13	2.0	9.0	0.4	-
R14	2.0	9.1	0.3	-
R15	0.6	2.7	0.1	-
R16	0.6	2.6	0.1	-
R17	0.8	3.6	0.2	-

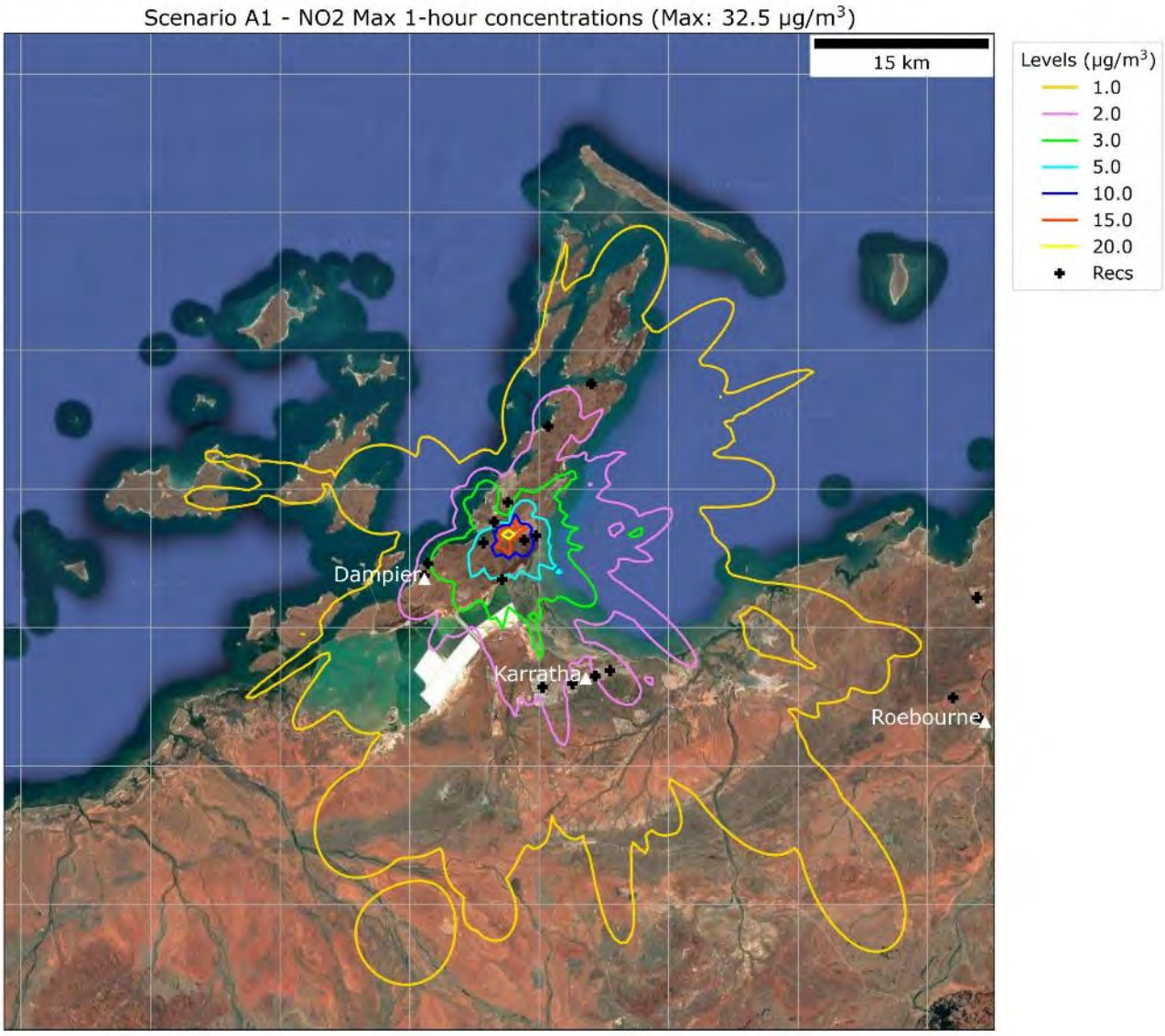

Figure 21. Contour levels of the maximum 1-hour concentrations of NO_2. Scenario A1.

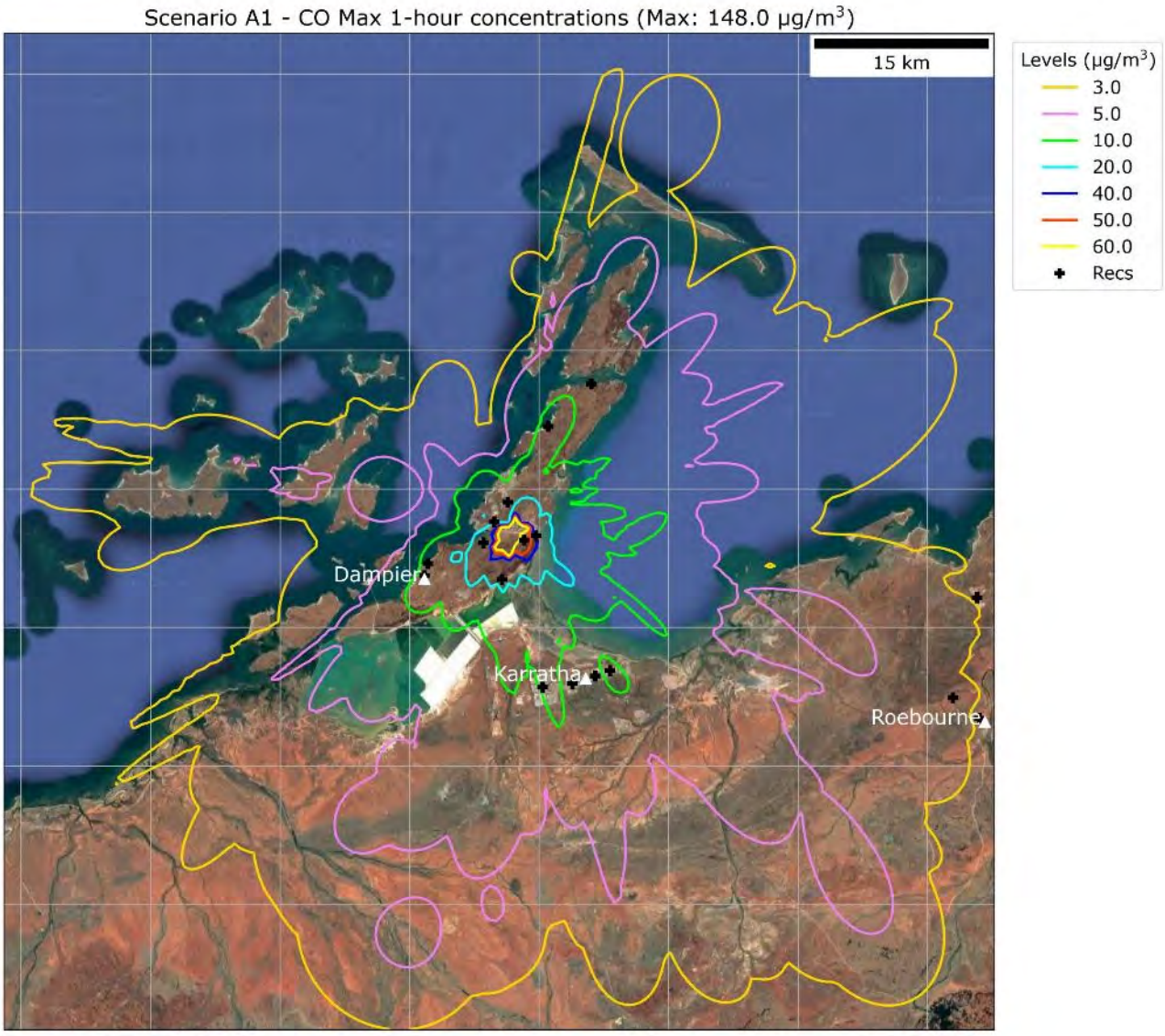

Figure 22. Contour levels of the maximum 1-hour concentrations of CO. Scenario A1.

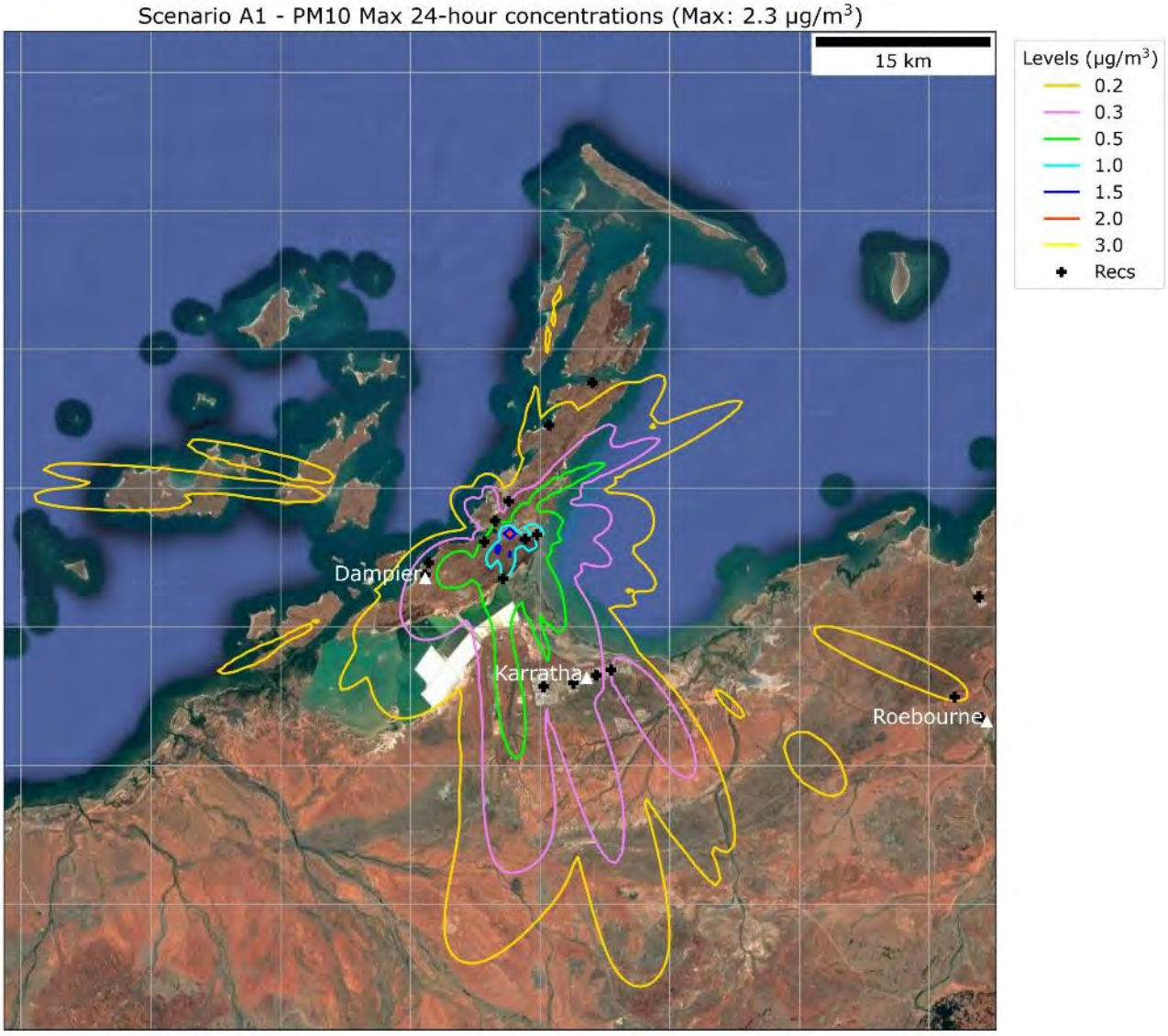

Figure 23. Contour levels of the maximum 24-hour concentrations of PM10. Scenario A1.

9.5 SCENARIO A4

The estimated frequency of scenario A4 is 0-5 times per year, and the release duration is less than one day (Table 4). In this scenario SO_2 is not emitted. The stream is composed by process gas, and its destination is the Syngas flare. The maximum concentrations calculated over the Cartesian receptors are summarised in Table 11, while those estimated at the sensitive receptors are reported in Table 12. All predicted concentrations are below the corresponding reference values.
The GLCs of the pollutants are represented from Figure 24 to Figure 26.

Table 11. Maximum concentrations over the Cartesian receptors. Scenario A4.

Pollutant	Statistics	E (m)	N (m)	Value (µg/m³)	ERPG-2 (µg/m³)	Value/ERPG-2 (%)
NO_2	Max 1h	476750	7718450	28.9	28211	0.10
CO	Max 1h	476750	7718450	131.9	400731	0.03
PM10	Max 24h	476750	7718450	12.4	50	24.86
SO_2	Max 1h	-	-	-	7857	-

Table 12. Maximum concentrations at the sensitive receptors. Scenario A4.

Receptor	NO_2 Max 1h (µg/m³)	CO Max 1h (µg/m³)	PM10 Max 24h (µg/m³)	SO_2 Max 1h (µg/m³)
R1	2.3	10.3	1.6	-
R2	2.5	11.2	2.1	-
R3	1.9	8.9	1.9	-
R4	10.3	47.1	8.6	-
R5	6.5	29.4	5.1	-
R6	1.5	6.6	0.8	-
R7	4.9	22.4	5.8	-
R8	4.7	21.2	2.7	-
R9	6.5	29.7	2.5	-
R10	1.6	7.3	0.9	-
R11	2.5	11.5	2.2	-
R12	1.6	7.2	1.9	-
R13	1.8	8.1	1.9	-
R14	1.7	7.9	1.7	-
R15	0.5	2.4	0.5	-
R16	0.5	2.3	0.8	-
R17	0.7	3.0	1.2	-

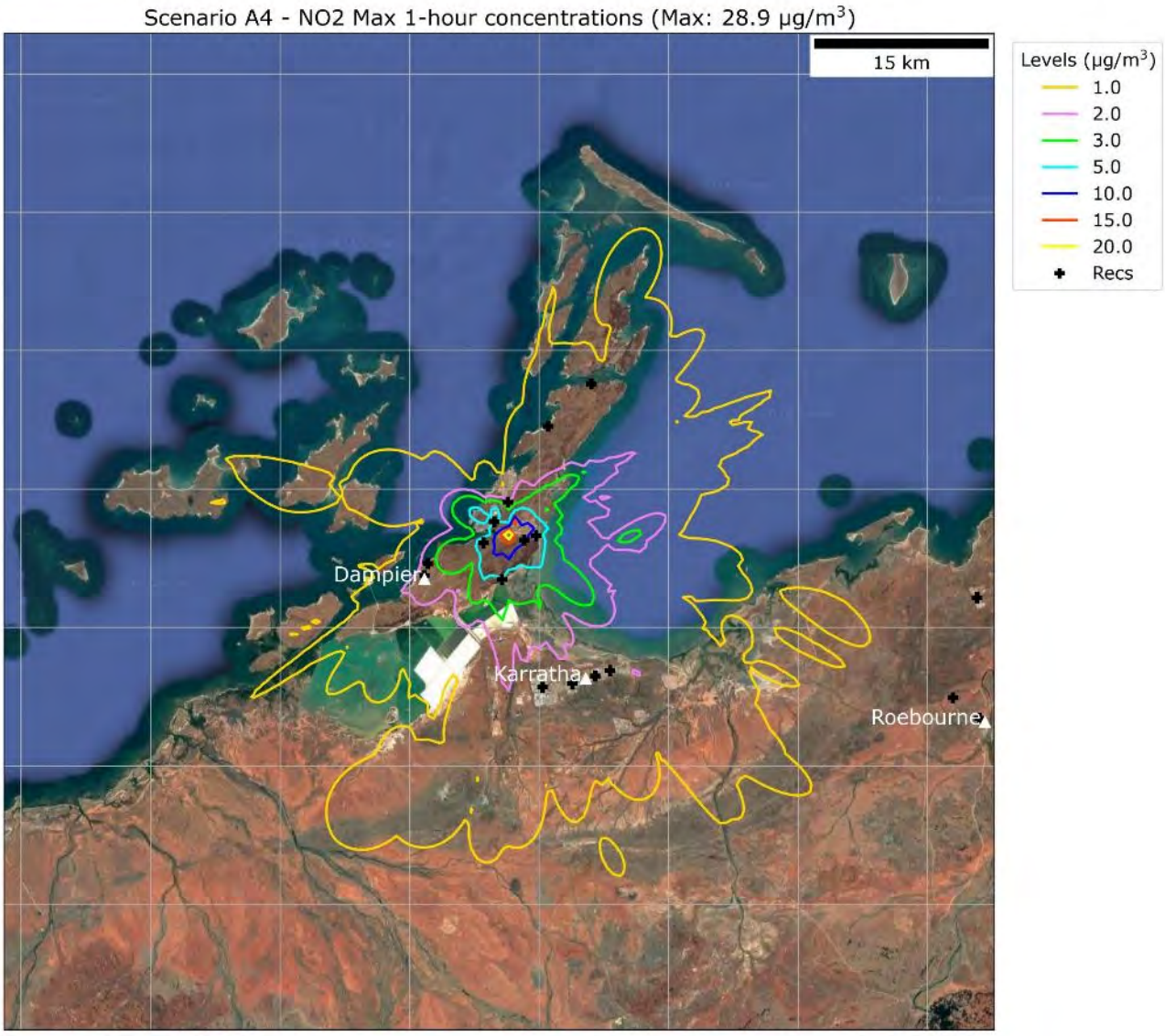

Figure 24. Contour levels of the maximum 1-hour concentrations of NO_2. Scenario A4.

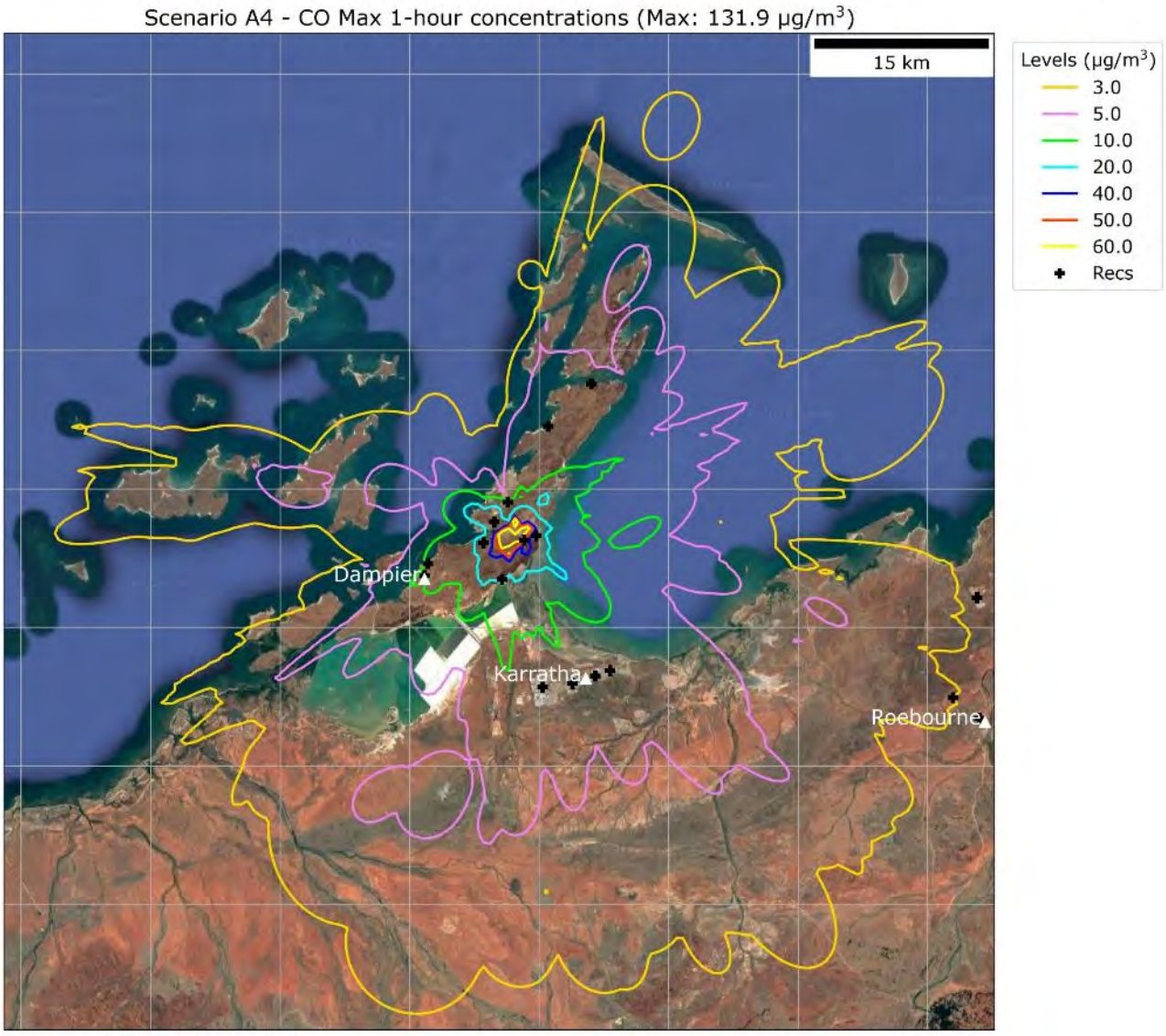

Figure 25. Contour levels of the maximum 1-hour concentrations of CO. Scenario A4.

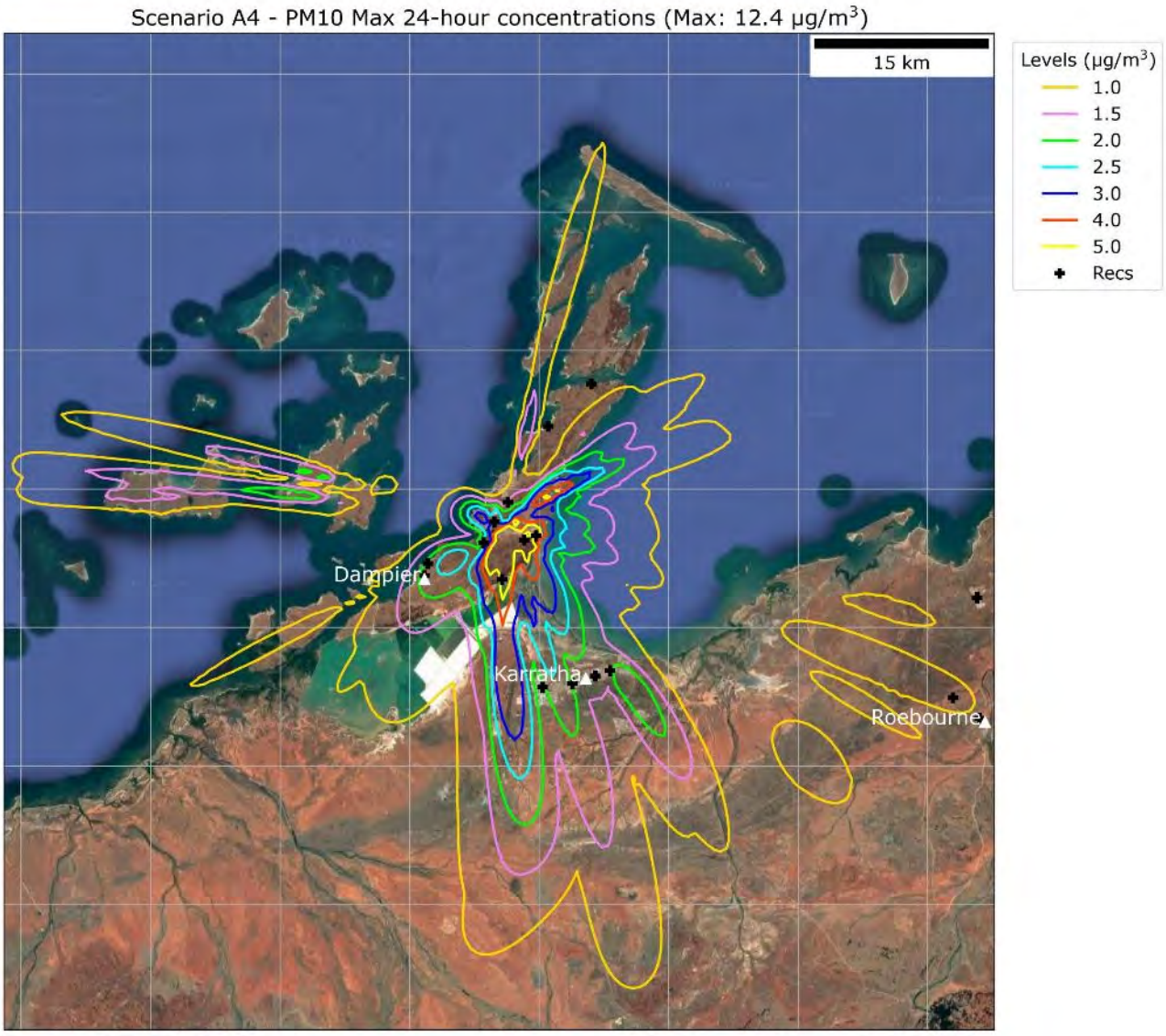

Figure 26. Contour levels of the maximum 24-hour concentrations of PM10. Scenario A4.

9.6 SCENARIO A8

The estimated frequency of scenario A8 is 1 time every 10 years, and the release duration is less than one hour (Table 4). The stream is mainly composed of ammonia, and its destination is the ammonia flare. The maximum concentrations calculated over the Cartesian receptors are summarised in Table 13, while those estimated at the sensitive receptors are reported in Table 14. All predicted concentrations are below the corresponding reference values.
The GLCs of the pollutants are represented from Figure 27 to Figure 30.

Table 13. Maximum concentrations over the Cartesian receptors. Scenario A8.

Pollutant	Statistics	E (m)	N (m)	Value (µg/m³)	ERPG-2 (µg/m³)	Value/ERPG-2 (%)
NO_2	Max 1h	476750	7718450	3795	28211	13.45
CO	Max 1h	476750	7718450	75.5	400731	0.02
PM10	Max 24h	476750	7718450	5.4	50	10.71
SO_2	Max 1h	476750	7718450	0.04	7857	0.0005

Table 14. Maximum concentrations at the sensitive receptors. Scenario A8.

Receptor	NO_2 Max 1h (µg/m³)	CO Max 1h (µg/m³)	PM10 Max 24h (µg/m³)	SO_2 Max 1h (µg/m³)
R1	569.7	11.3	0.87	0.006
R2	494.0	9.8	1.01	0.005
R3	311.7	6.2	0.91	0.003
R4	2359.7	47.0	3.64	0.024
R5	1196.6	23.8	1.95	0.012
R6	325.7	6.5	0.38	0.003
R7	832.8	16.6	2.57	0.008
R8	772.5	15.4	1.42	0.008
R9	1123.9	22.4	1.13	0.011
R10	269.2	5.4	0.39	0.003
R11	419.8	8.4	0.69	0.004
R12	302.0	6.0	0.94	0.003
R13	262.9	5.2	0.98	0.003
R14	284.3	5.7	0.76	0.003
R15	94.6	1.9	0.29	0.001
R16	85.7	1.7	0.39	0.001
R17	104.8	2.1	0.50	0.001

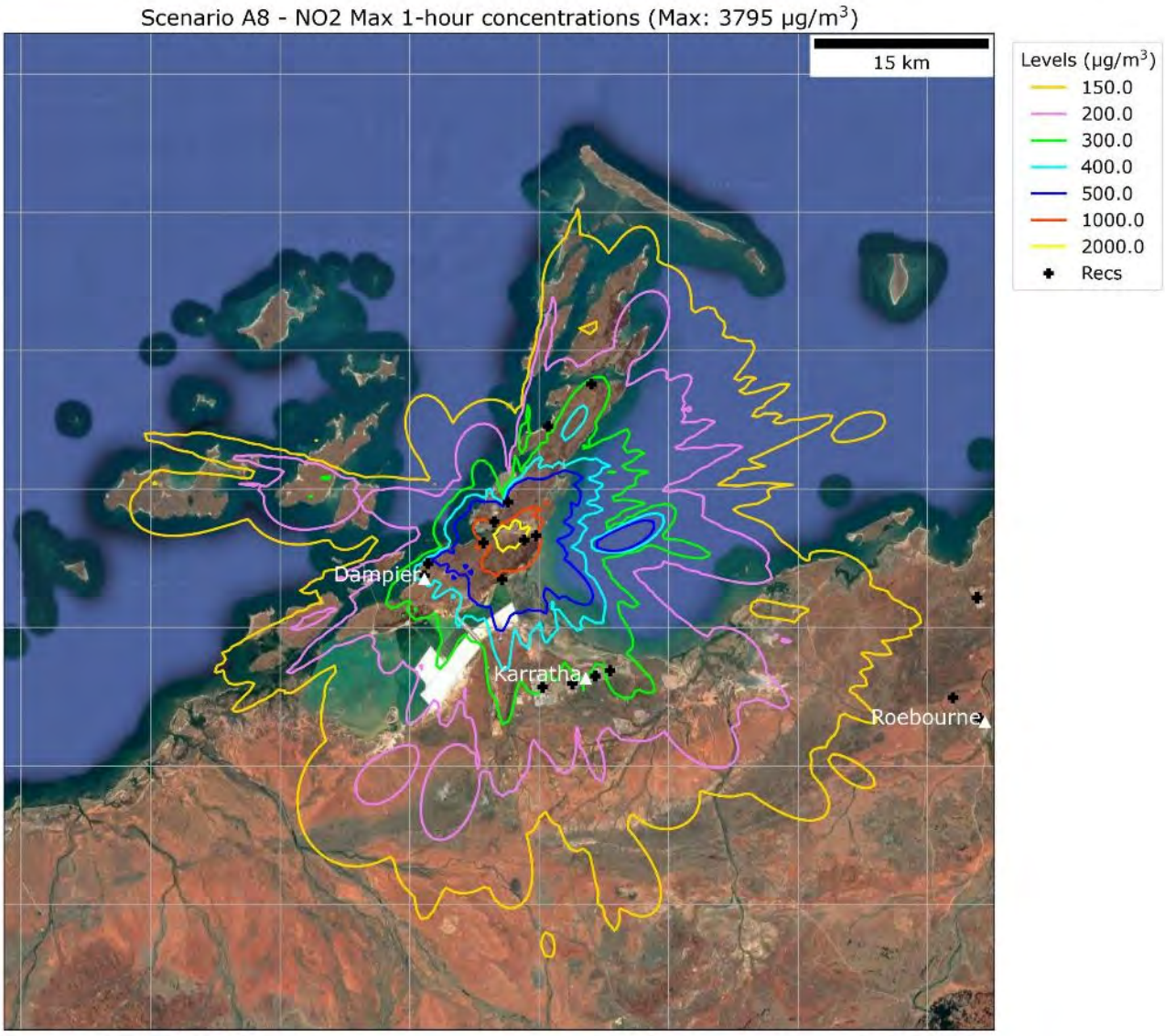

Figure 27. Contour levels of the maximum 1-hour concentrations of NO_2. Scenario A8.

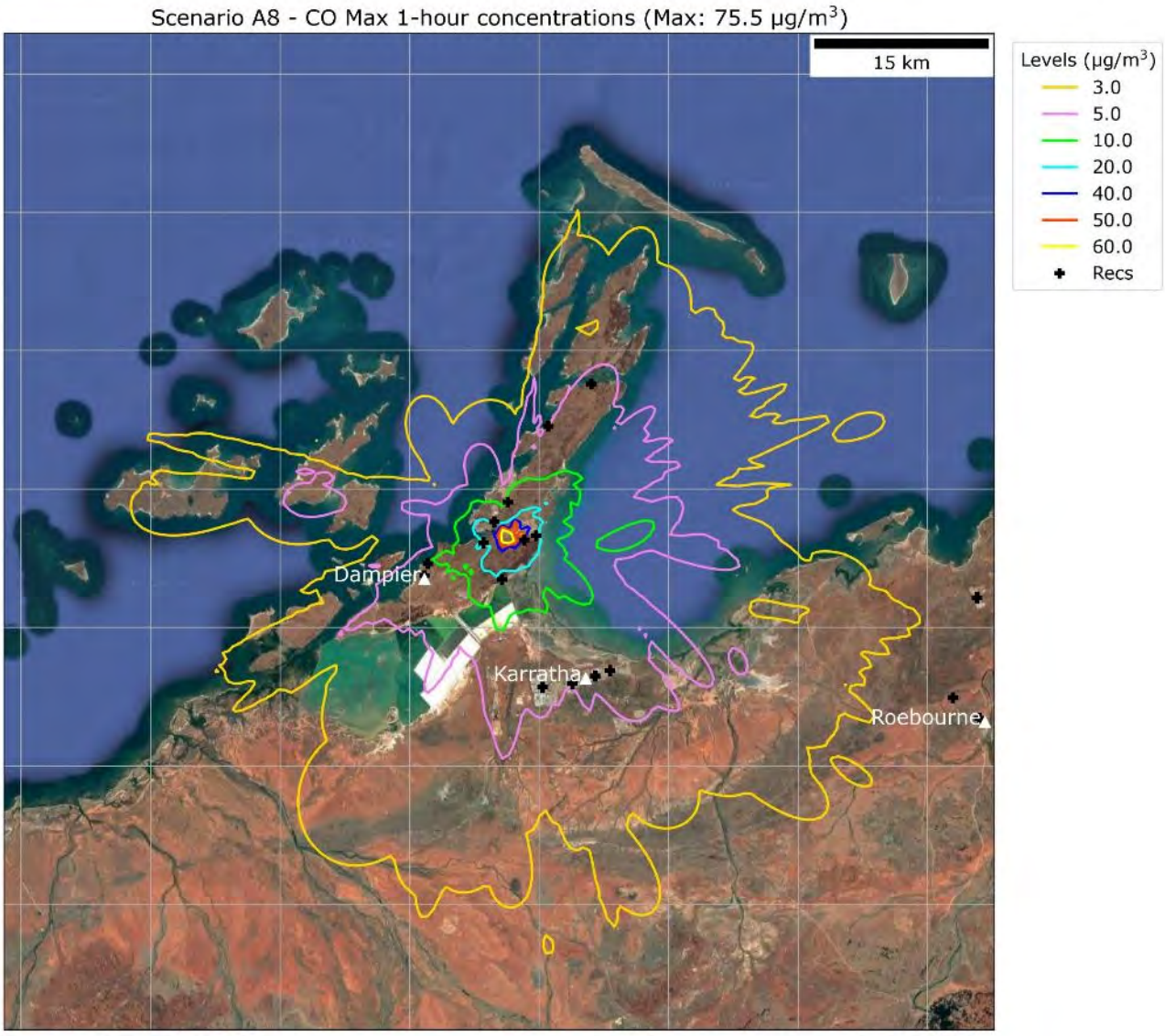

Figure 28. Contour levels of the maximum 1-hour concentrations of CO. Scenario A8.

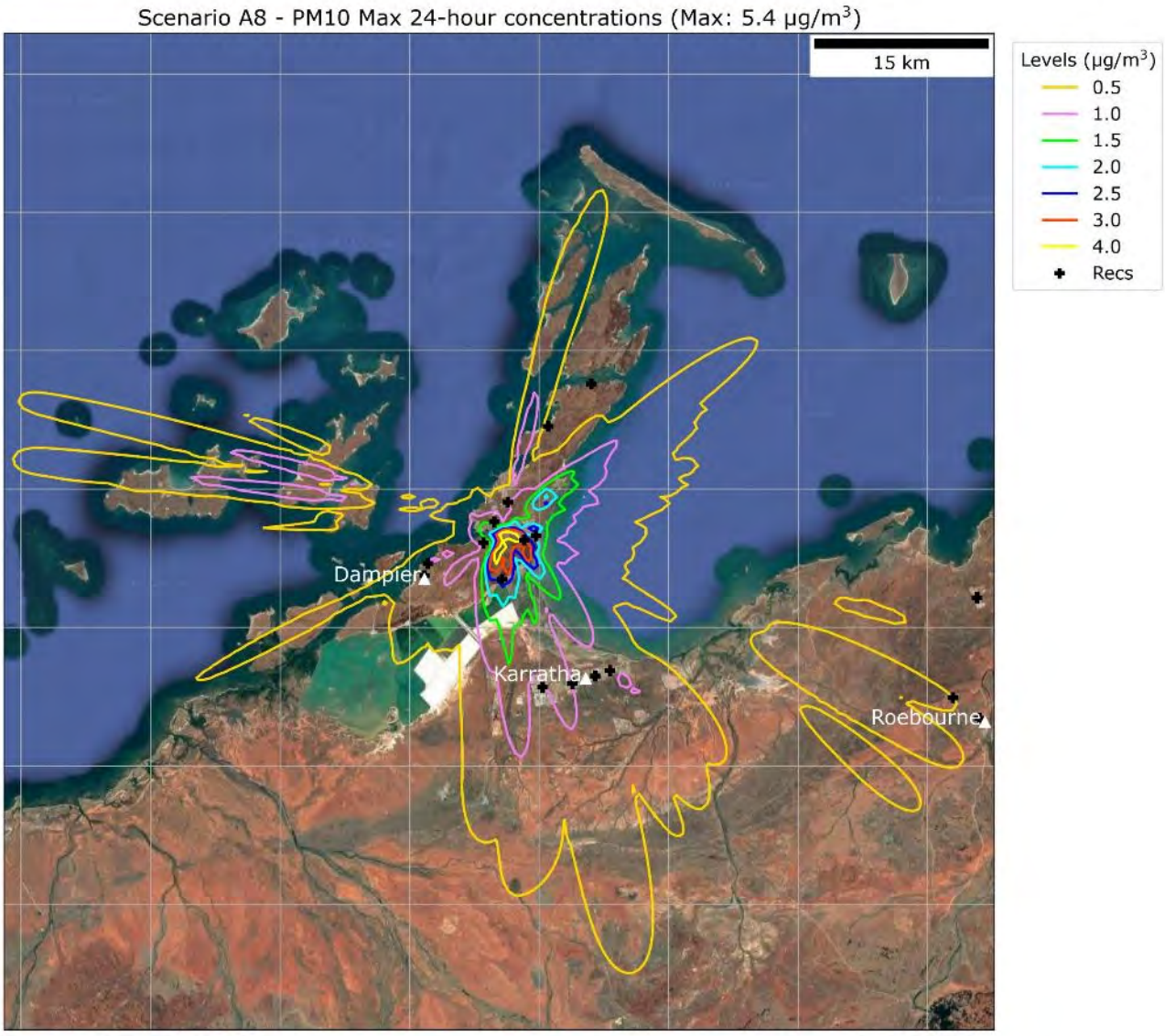

Figure 29. Contour levels of the maximum 24-hour concentrations of PM10. Scenario A8.

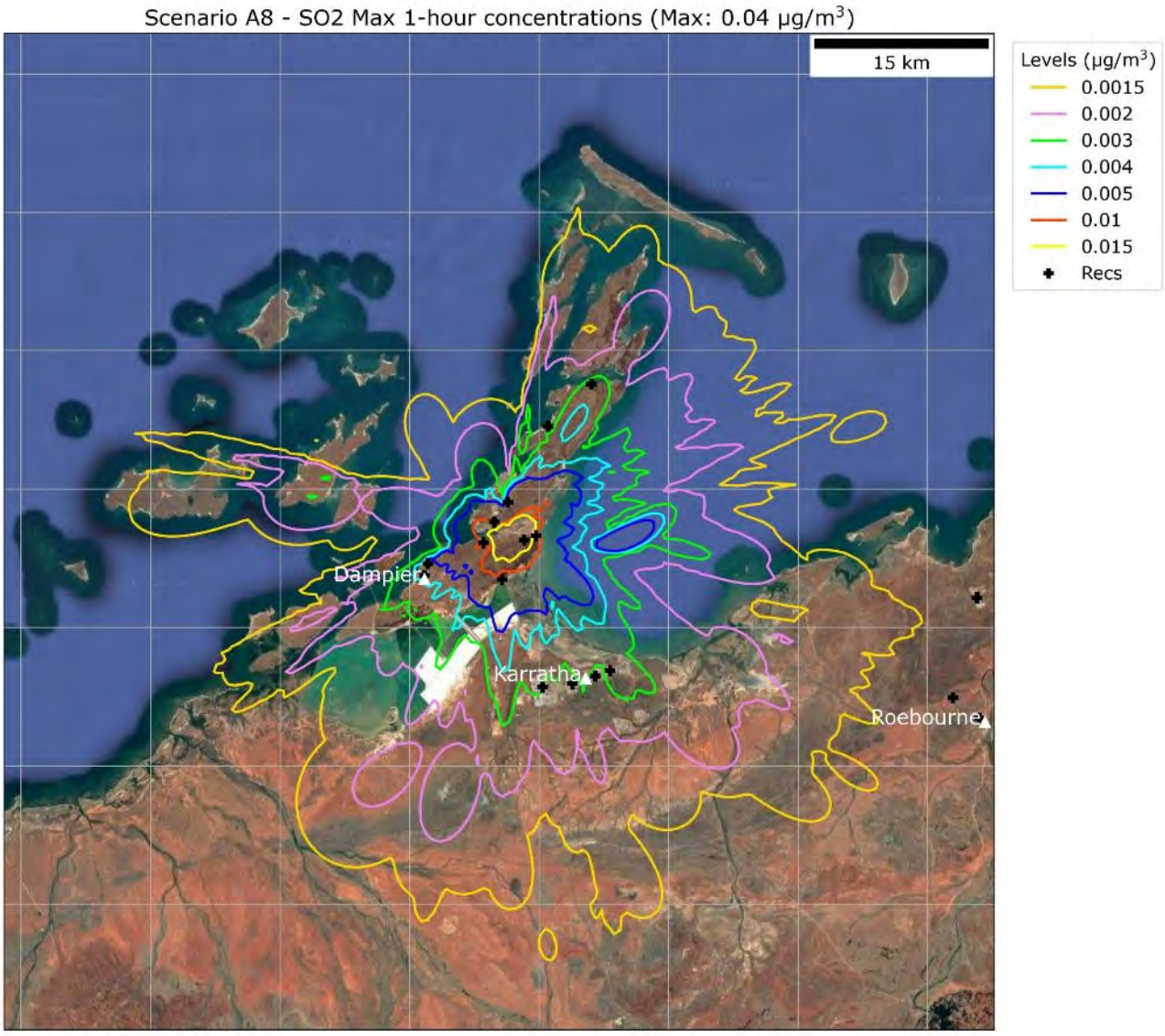

Figure 30. Contour levels of the maximum 1-hour concentrations of SO_2. Scenario A8.

9.7 SCENARIO U6

Scenario U6 is judged as a remote event (1 time per 10 years), and its release duration is about 10 minutes (Table 4). The stream is mainly composed of ammonia, and its destination is the Secondary Urea Flare. The maximum concentrations calculated over the Cartesian receptors are summarised in Table 15, while those estimated at the sensitive receptors are reported in Table 16. All predicted concentrations are below the corresponding reference values.
The GLCs of the pollutants are represented from Figure 31 to Figure 34.

Table 15. Maximum concentrations over the Cartesian receptors. Scenario U6.

Pollutant	Statistics	E (m)	N (m)	Value (µg/m³)	ERPG-2 (µg/m³)	Value/ERPG-2 (%)
NO_2	Max 1h	476250	7718950	2354	28211	8.98
CO	Max 1h	476250	7718950	52.3	400731	0.01
PM10	Max 24h	476250	7718950	3.9	50	7.88
SO_2	Max 1h	476250	7718950	0.04	7857	0.0005

Table 16. Maximum concentrations at the sensitive receptors. Scenario U6.

Receptor	NO_2 Max 1h (µg/m³)	CO Max 1h (µg/m³)	PM10 Max 24h (µg/m³)	SO_2 Max 1h (µg/m³)
R1	431.5	8.9	1.44	0.006
R2	225.0	4.6	0.75	0.003
R3	97.2	2.0	0.43	0.001
R4	626.4	12.9	2.10	0.009
R5	600.2	12.4	1.72	0.009
R6	128.7	2.7	0.26	0.002
R7	318.7	6.6	0.71	0.005
R8	780.9	16.1	0.73	0.011
R9	523.2	10.8	0.86	0.008
R10	148.3	3.1	0.36	0.002
R11	178.8	3.7	0.35	0.003
R12	81.6	1.7	0.29	0.001
R13	125.4	2.6	0.37	0.002
R14	117.6	2.4	0.27	0.002
R15	30.3	0.6	0.11	0.000
R16	23.8	0.5	0.10	0.000
R17	31.4	0.6	0.11	0.000

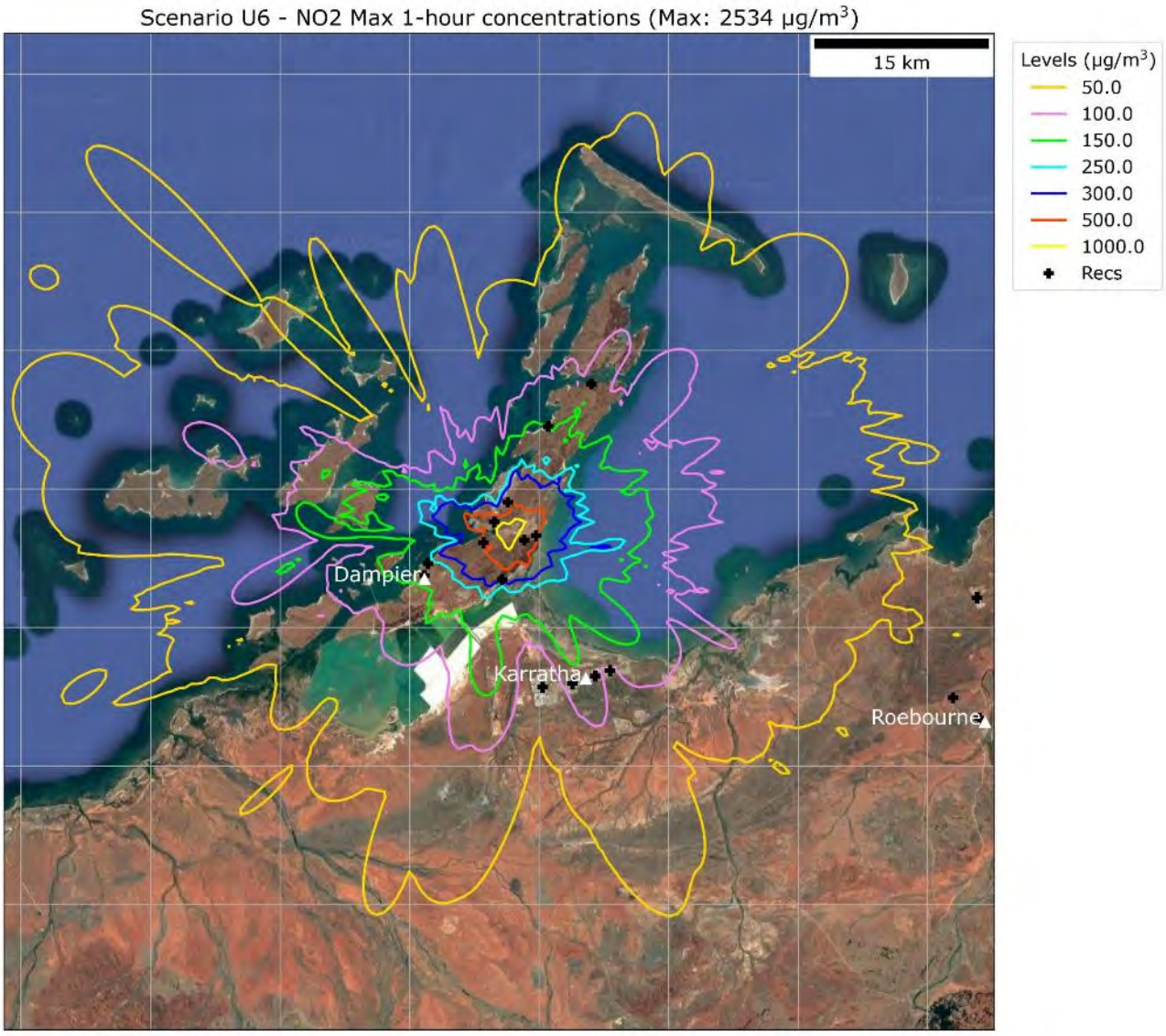

Figure 31. Contour levels of the maximum 1-hour concentrations of NO_2. Scenario U6.

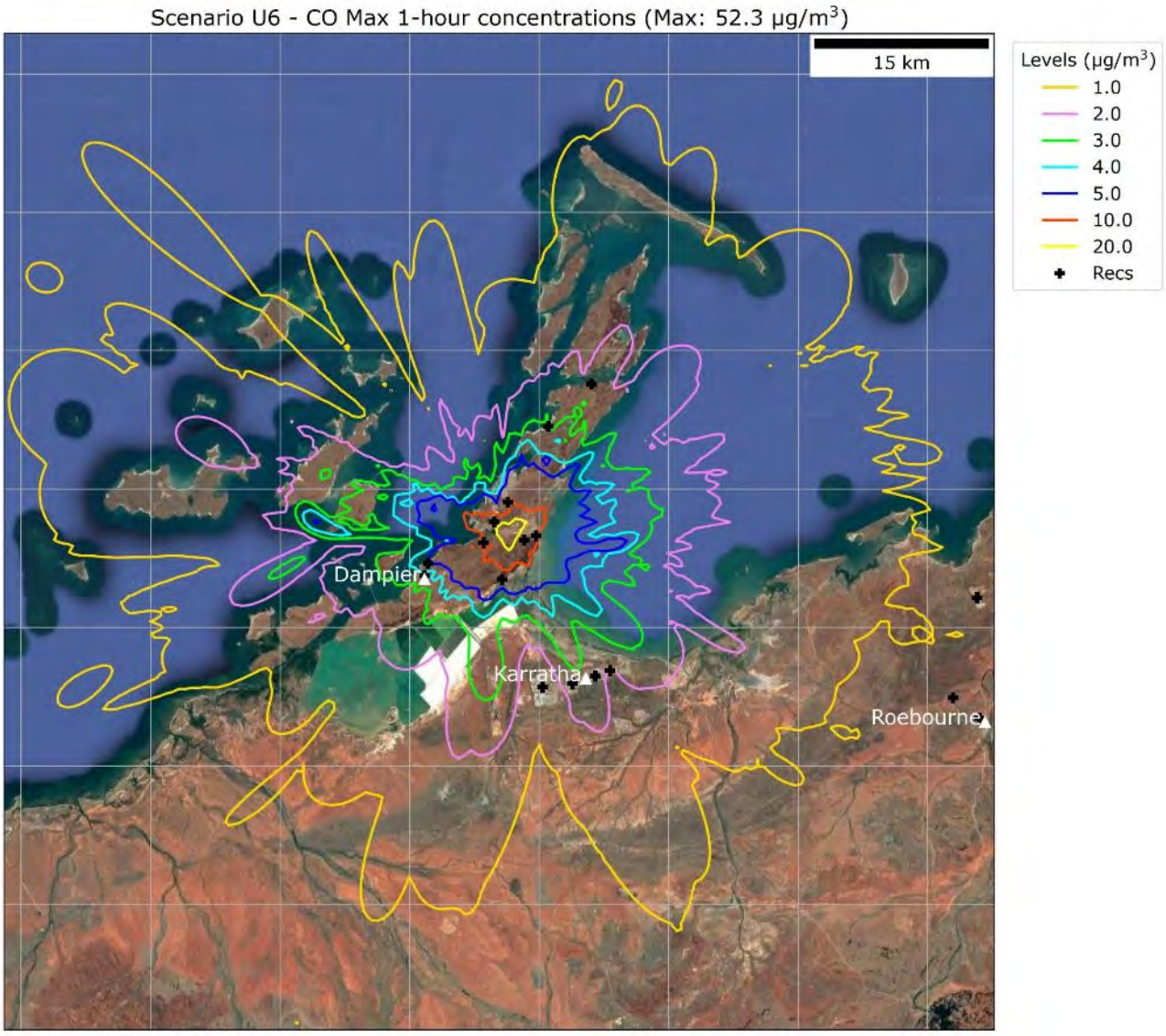

Figure 32. Contour levels of the maximum 1-hour concentrations of CO. Scenario U6.

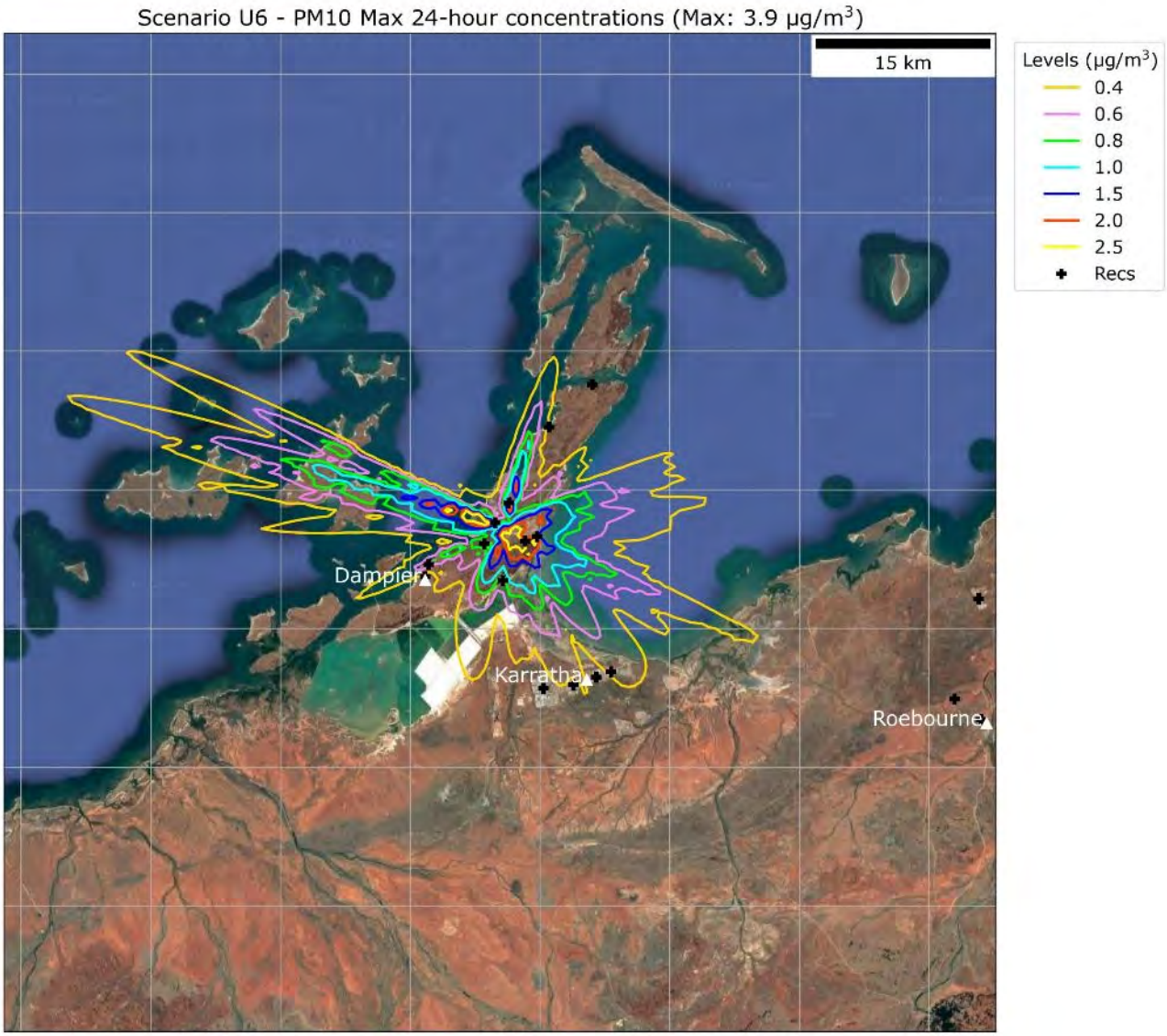

Figure 33. Contour levels of the maximum 24-hour concentrations of PM10. Scenario U6.

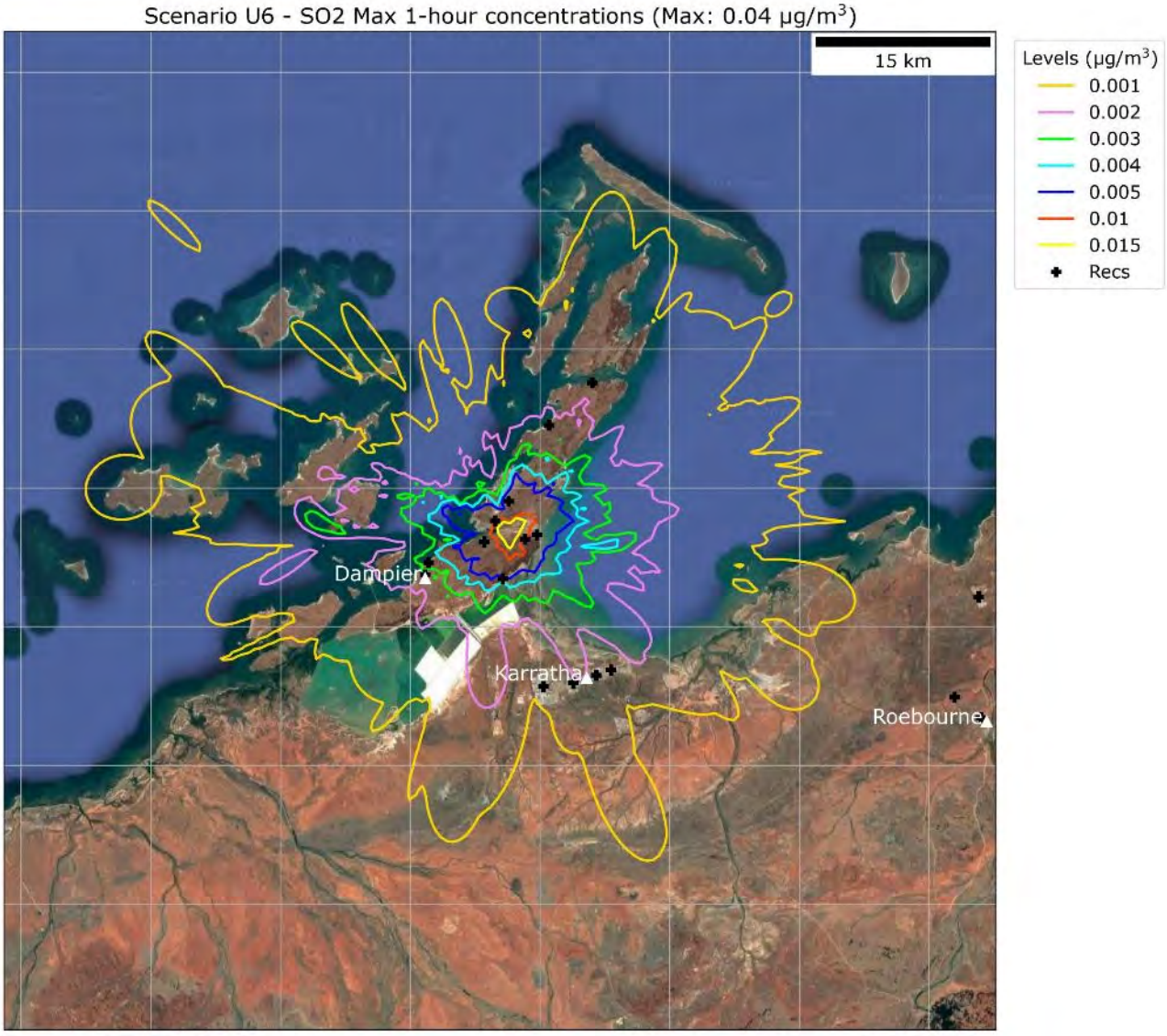

Figure 34. Contour levels of the maximum 1-hour concentrations of SO_2. Scenario U6.

9.8 SCENARIO U8

Scenario U8 is an event with a very low frequency (0-2 times per year), and its release duration is about 30 minutes (Table 4). The stream is mainly composed of ammonia, and its destination is the Secondary Urea Flare. The maximum concentrations calculated over the Cartesian receptors are summarised in Table 17, while those estimated at the sensitive receptors are reported in Table 18. All predicted concentrations are below the corresponding reference values.
The GLCs of the pollutants are represented from Figure 35 to Figure 38.

Table 17. Maximum concentrations over the Cartesian receptors. Scenario U8.

Pollutant	Statistics	E (m)	N (m)	Value (µg/m³)	ERPG-2 (µg/m³)	Value/ERPG-2 (%)
NO_2	Max 1h	476250	7718950	1030	28211	3.65
CO	Max 1h	476250	7718950	23.4	400731	0.01
PM10	Max 24h	476250	7718450	3.5	50	7.07
SO_2	Max 1h	476250	7718950	0.03	7857	0.0004

Table 18. Maximum concentrations at the sensitive receptors. Scenario U8.

Receptor	NO_2 Max 1h (µg/m³)	CO Max 1h (µg/m³)	PM10 Max 24h (µg/m³)	SO_2 Max 1h (µg/m³)
R1	288.0	6.5	1.27	0.008
R2	94.1	2.1	0.64	0.003
R3	32.6	0.7	0.20	0.001
R4	289.0	6.6	2.36	0.008
R5	187.9	4.3	1.32	0.005
R6	42.3	1.0	0.21	0.001
R7	123.6	2.8	0.54	0.003
R8	680.2	15.4	0.99	0.019
R9	281.8	6.4	0.70	0.008
R10	58.2	1.3	0.33	0.002
R11	52.5	1.2	0.22	0.001
R12	25.0	0.6	0.11	0.001
R13	41.0	0.9	0.16	0.001
R14	41.9	0.9	0.17	0.001
R15	14.0	0.3	0.09	0.000
R16	10.4	0.2	0.06	0.000
R17	11.6	0.3	0.09	0.000

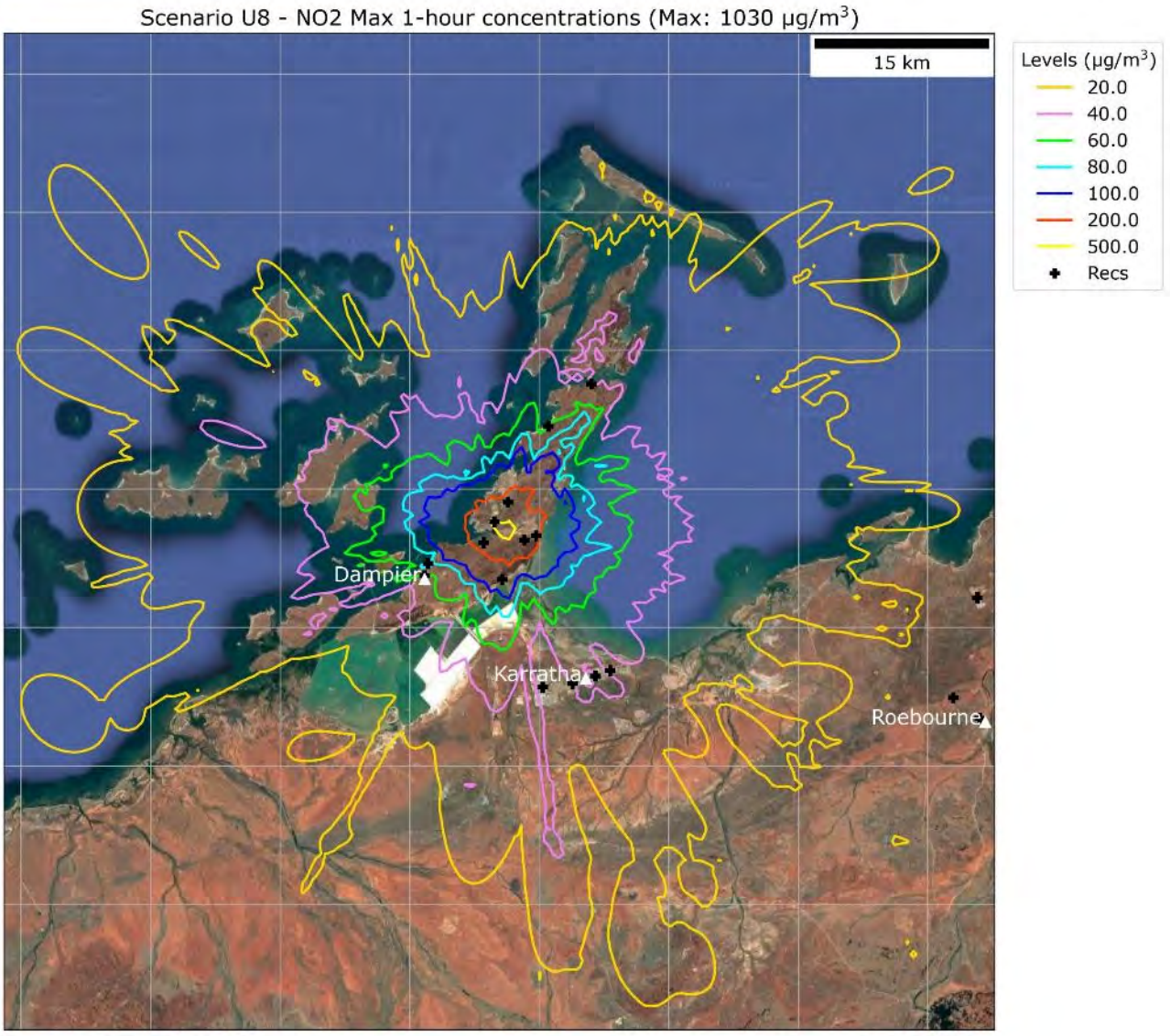

Figure 35. Contour levels of the maximum 1-hour concentrations of NO_2. Scenario U8.

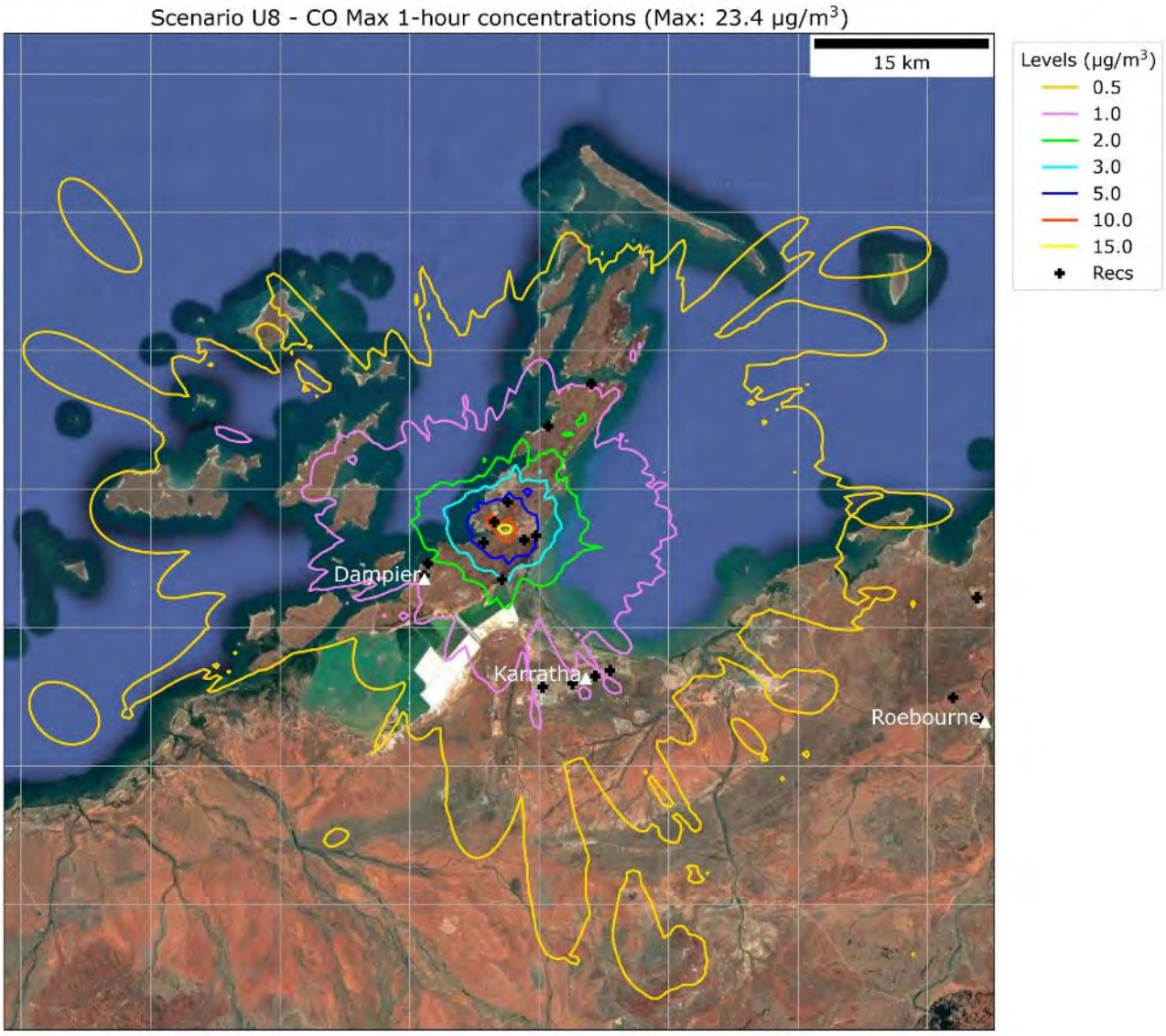

Figure 36. Contour levels of the maximum 1-hour concentrations of CO. Scenario U8.

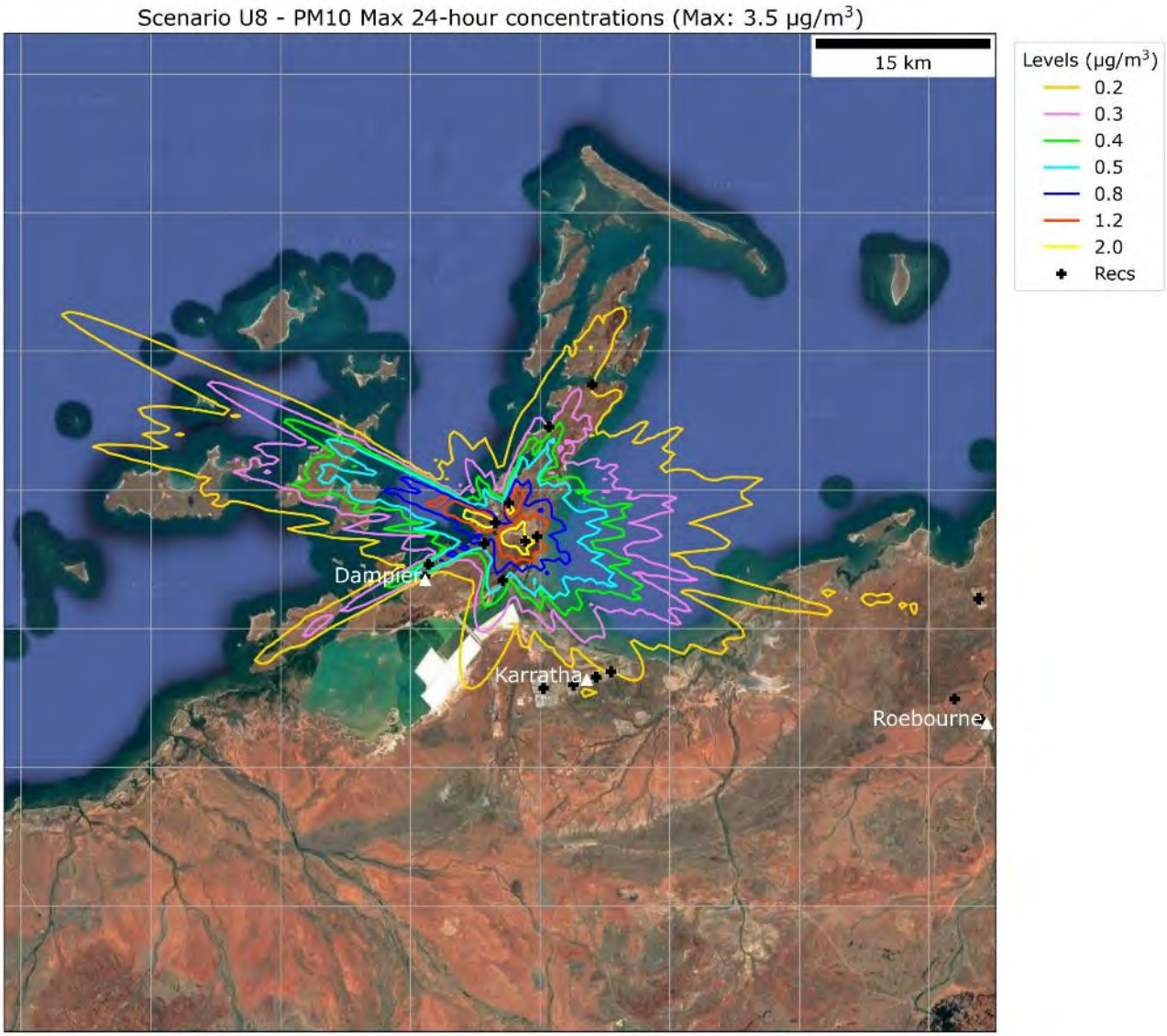

Figure 37. Contour levels of the maximum 24-hour concentrations of PM10. Scenario U8.

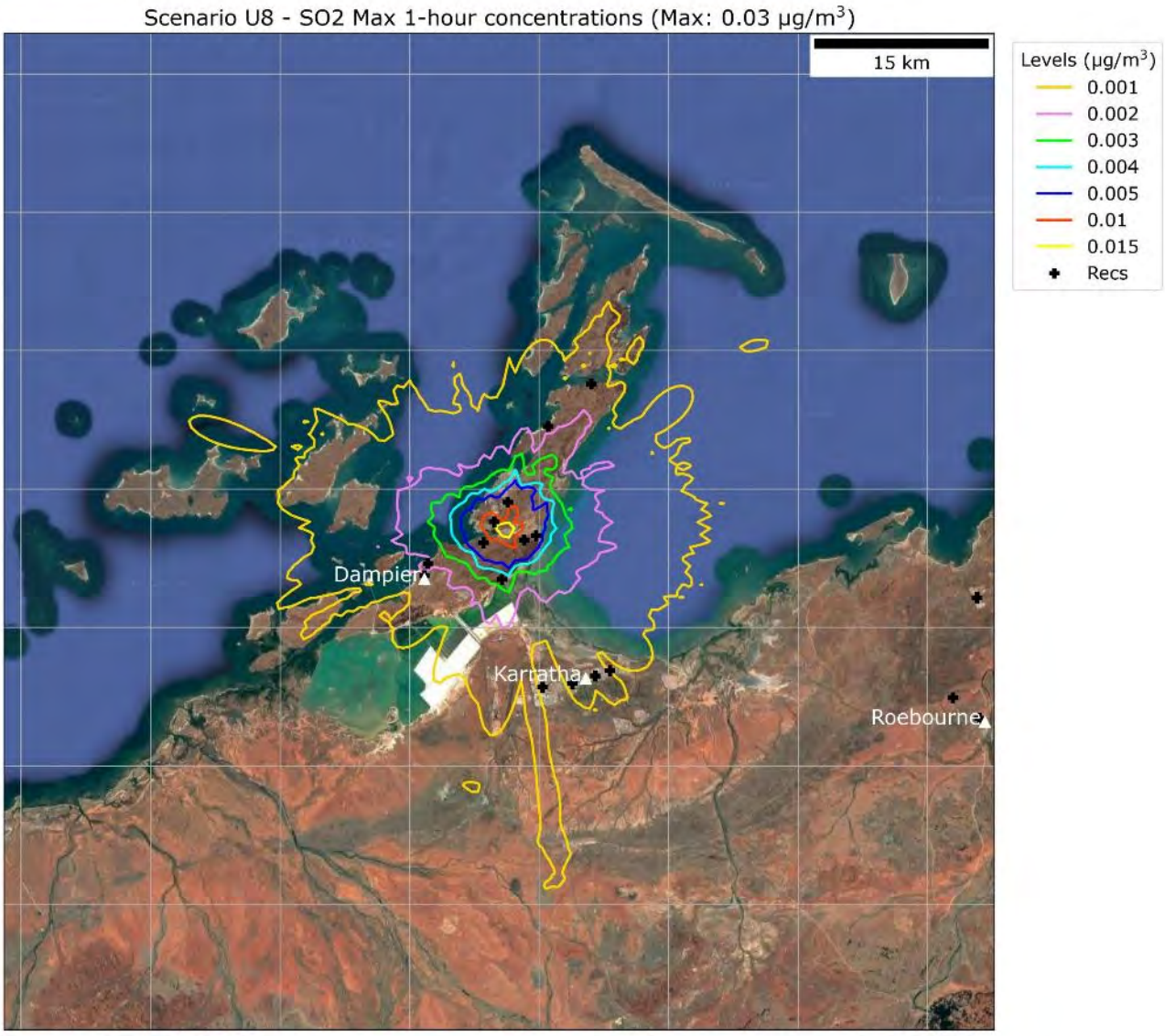

Figure 38. Contour levels of the maximum 1-hour concentrations of SO_2. Scenario U8.

9.9 SCENARIO U9

Scenario U9 is an event with a very low frequency (0-2 times per year), and its release duration is about 60 minutes (Table 4). The stream is mainly composed by ammonia, and its destination is the Secondary Urea Flare .The maximum concentrations calculated over the Cartesian receptors are summarised in Table 17Table 19, while those estimated at the sensitive receptors are reported in Table 18Table 20. All predicted concentrations are below the corresponding reference values.
The GLCs of the pollutants are represented from Figure 39to Figure 38Figure 42.

Table 19. Maximum concentrations over the Cartesian receptors. Scenario U9.

Pollutant	Statistics	E (m)	N (m)	Value (µg/m^3)	ERPG-2 (µg/m^3)	Value/ERPG-2 (%)
NO_2	Max 1h	476250	7718950	1051	28211	3.73
CO	Max 1h	476250	7718950	24.0	400731	0.01
PM10	Max 24h	474250	7719950	4.4	50	8.75
SO_2	Max 1h	476250	7718950	0.03	7857	0.0004

Table 20. Maximum concentrations at the sensitive receptors. Scenario U9.

Receptor	NO_2 Max 1h (µg/m^3)	CO Max 1h (µg/m^3)	PM10 Max 24h (µg/m^3)	SO_2 Max 1h (µg/m^3)
R1	302.1	6.9	1.60	0.009
R2	96.8	2.2	0.80	0.003
R3	32.9	0.7	0.26	0.001
R4	296.0	6.7	2.99	0.008
R5	194.6	4.4	1.65	0.006
R6	42.3	1.0	0.26	0.001
R7	122.0	2.8	0.68	0.003
R8	712.3	16.2	1.28	0.020
R9	288.7	6.6	0.89	0.008
R10	57.8	1.3	0.41	0.002
R11	54.8	1.2	0.27	0.002
R12	25.5	0.6	0.14	0.001
R13	43.0	1.0	0.21	0.001
R14	42.2	1.0	0.21	0.001
R15	14.6	0.3	0.11	0.000
R16	10.3	0.2	0.08	0.000
R17	11.5	0.3	0.11	0.000

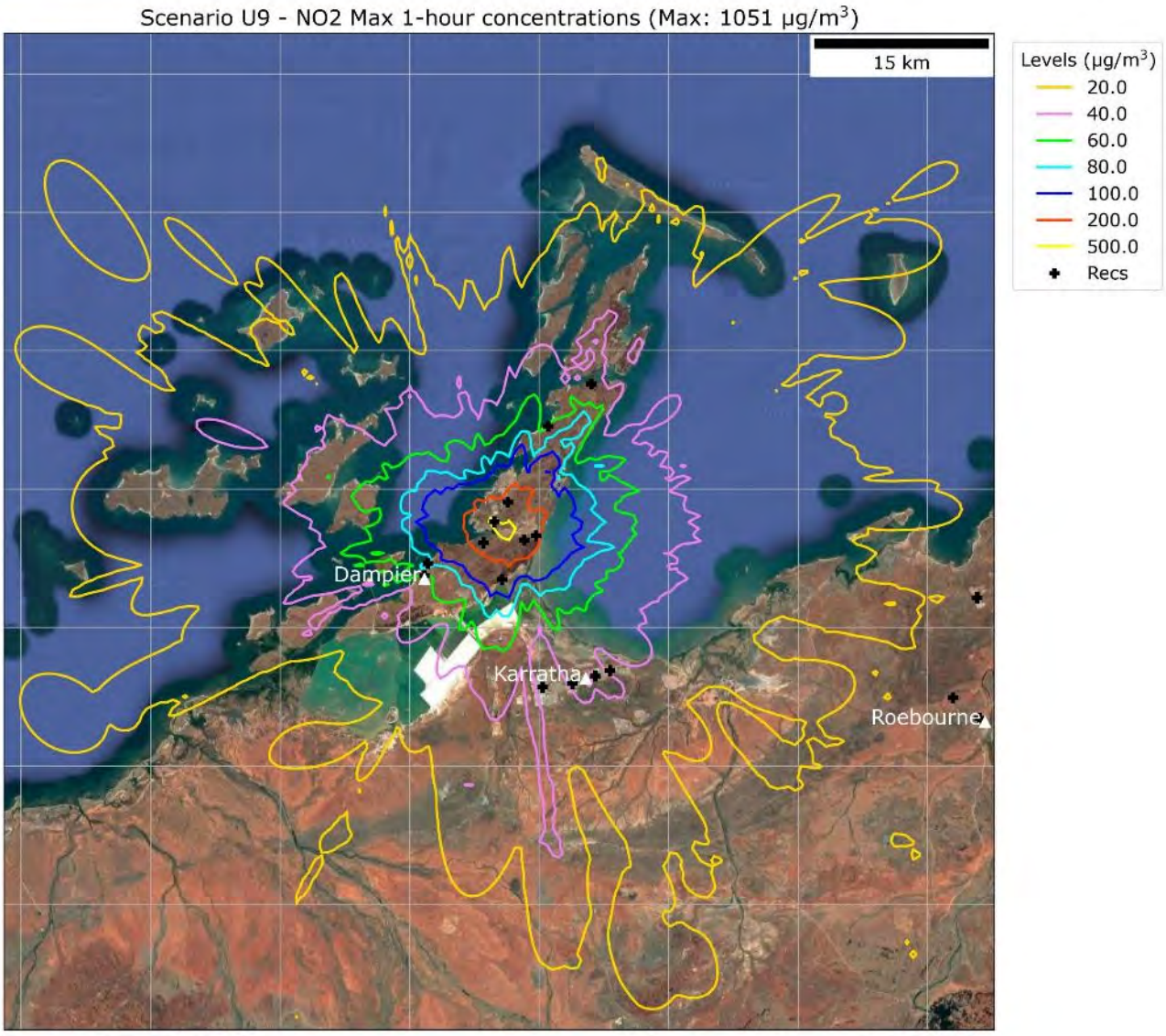

Figure 39. Contour levels of the maximum 1-hour concentrations of NO_2. Scenario U9.

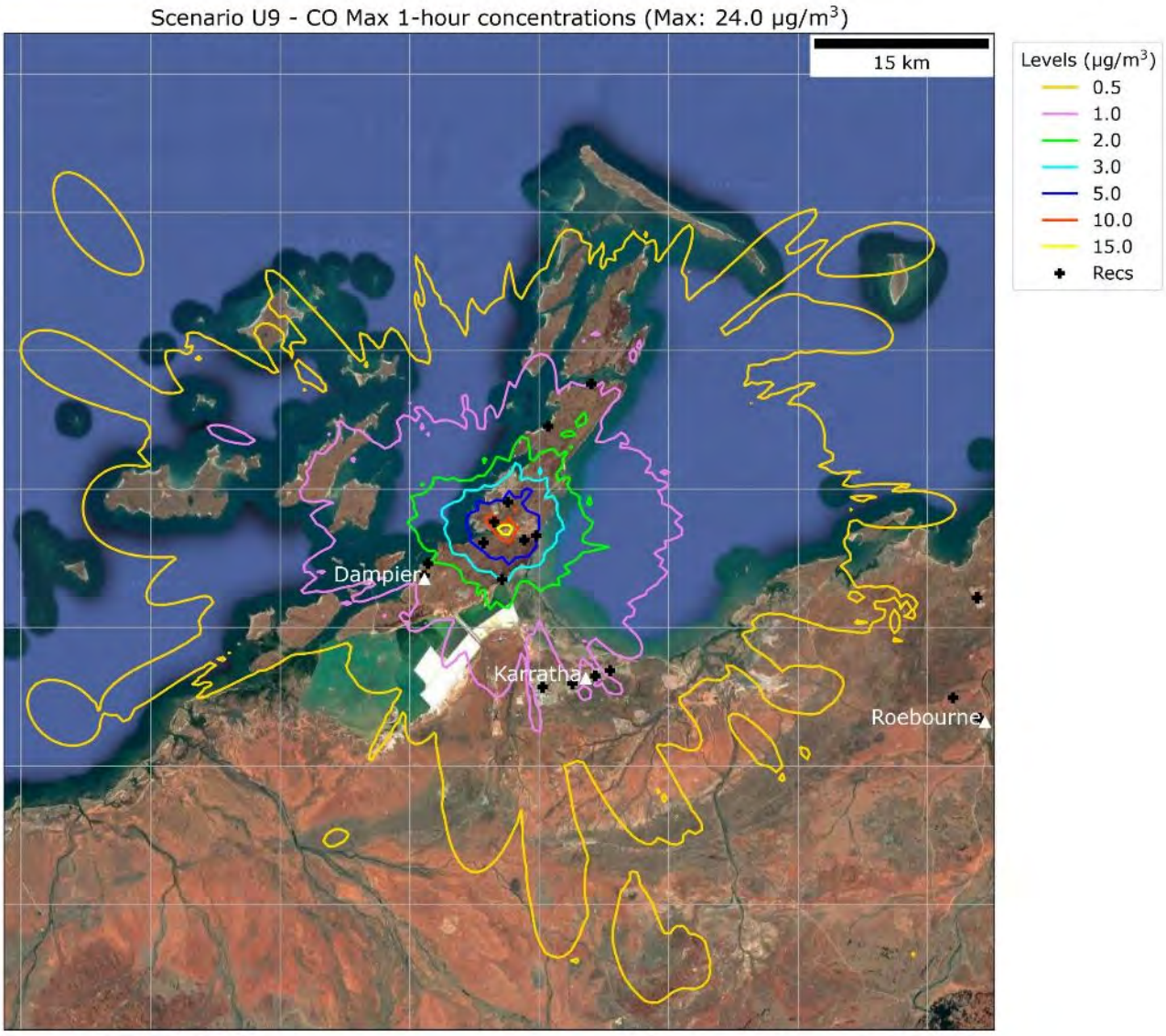

Figure 40. Contour levels of the maximum 1-hour concentrations of CO. Scenario U9.

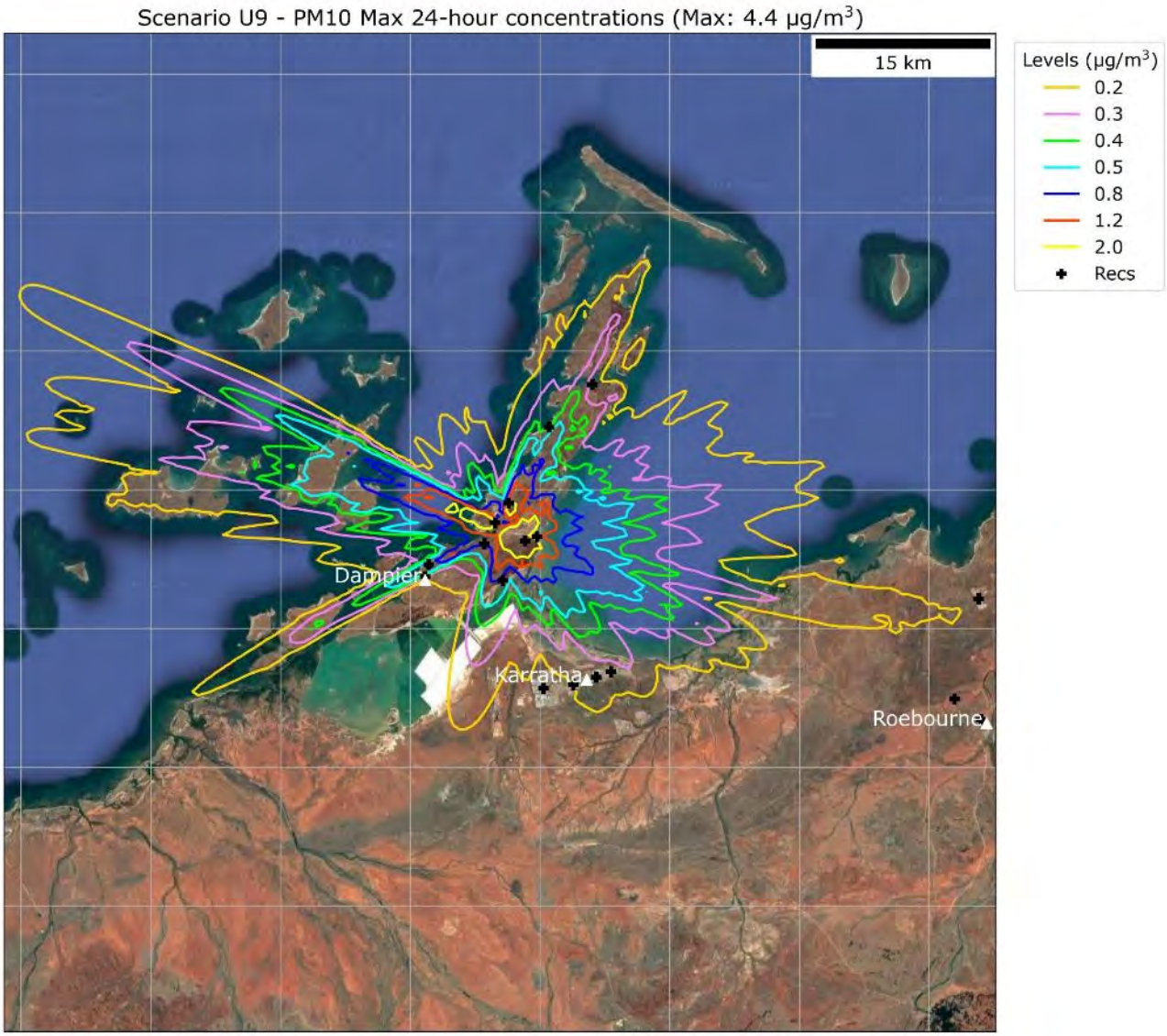

Figure 41. Contour levels of the maximum 24-hour concentrations of PM10. Scenario U9.

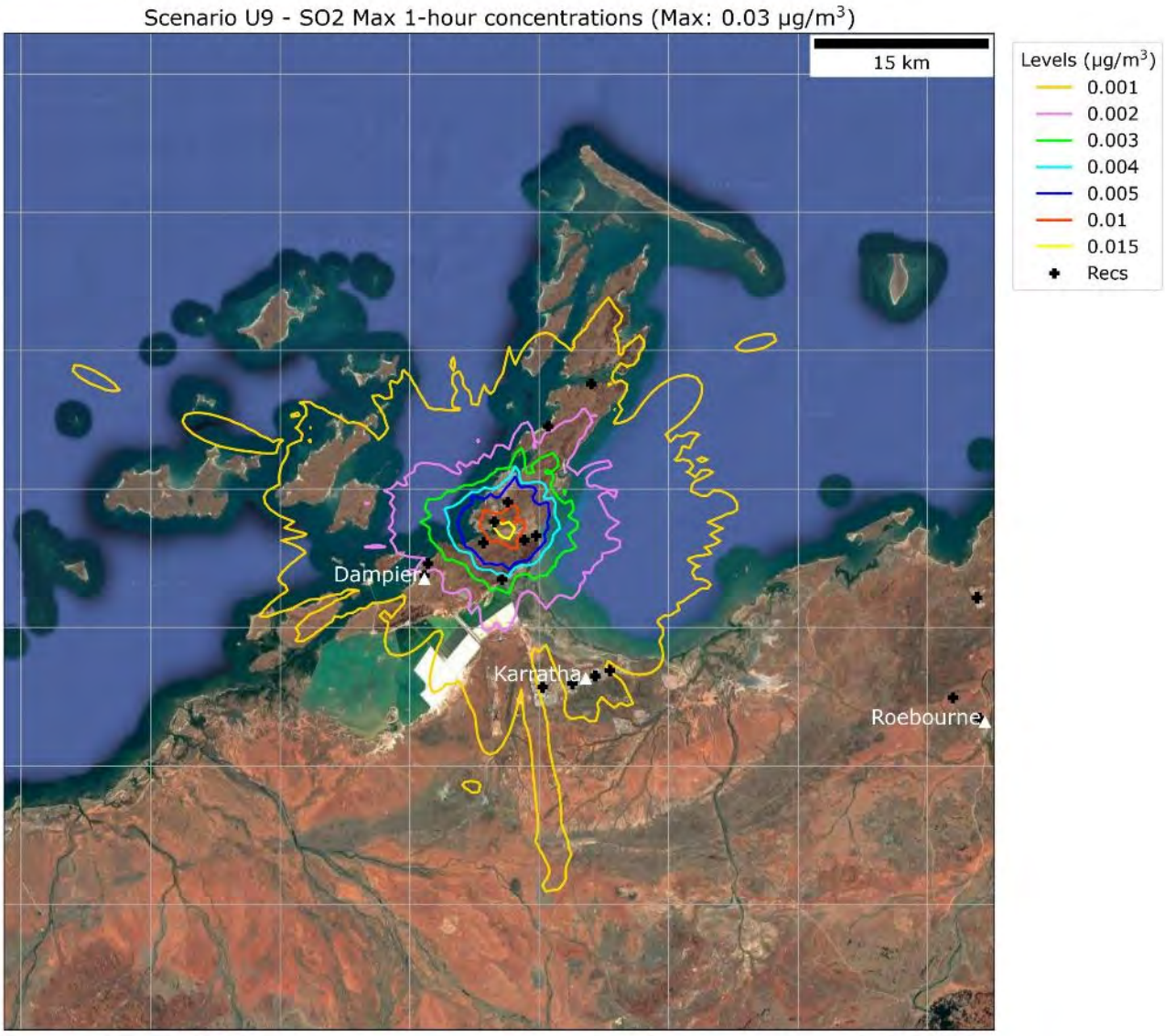

Figure 42. Contour levels of the maximum 1-hour concentrations of SO_2. Scenario U9.

9.10 SCENARIO S2

The estimated frequency of scenario S2 is 1 time every 10 years, and the release duration is less than one hour (Table 4). The stream is mainly composed by ammonia, and its destination is the ammonia storage flare. The maximum concentrations calculated over the Cartesian receptors are summarised in Table 21, while those estimated at the sensitive receptors are reported in Table 22. All predicted concentrations are below the corresponding reference values.
The GLCs of the pollutants are represented from Figure 43 to Figure 46.

Table 21. Maximum concentrations over the Cartesian receptors. Scenario S2.

Pollutant	Statistics	E (m)	N (m)	Value (µg/m^3)	ERPG-2 (µg/m^3)	Value/ERPG-2 (%)
NO_2	Max 1h	476250	7718950	2403	28211	8.52
CO	Max 1h	476250	7718950	49.2	400731	0.01
PM10	Max 24h	475250	7719450	4.6	50	9.14
SO_2	Max 1h	476250	7718950	0.03	7857	0.0004

Table 22. Maximum concentrations at the sensitive receptors. Scenario S2.

Receptor	NO_2 Max 1h (µg/m^3)	CO Max 1h (µg/m^3)	PM10 Max 24h (µg/m^3)	SO_2 Max 1h (µg/m^3)
R1	323.0	6.6	0.88	0.004
R2	70.8	1.4	0.35	0.001
R3	24.2	0.5	0.07	0.000
R4	212.7	4.4	0.95	0.003
R5	185.6	3.8	0.93	0.002
R6	35.2	0.7	0.10	0.000
R7	74.2	1.5	0.21	0.001
R8	695.5	14.2	5.03	0.009
R9	195.4	4.0	0.26	0.003
R10	48.0	1.0	0.17	0.001
R11	64.2	1.3	0.16	0.001
R12	41.6	0.9	0.07	0.001
R13	32.2	0.7	0.09	0.000
R14	26.0	0.5	0.08	0.000
R15	8.5	0.2	0.03	0.000
R16	7.9	0.2	0.04	0.000
R17	10.7	0.2	0.06	0.000

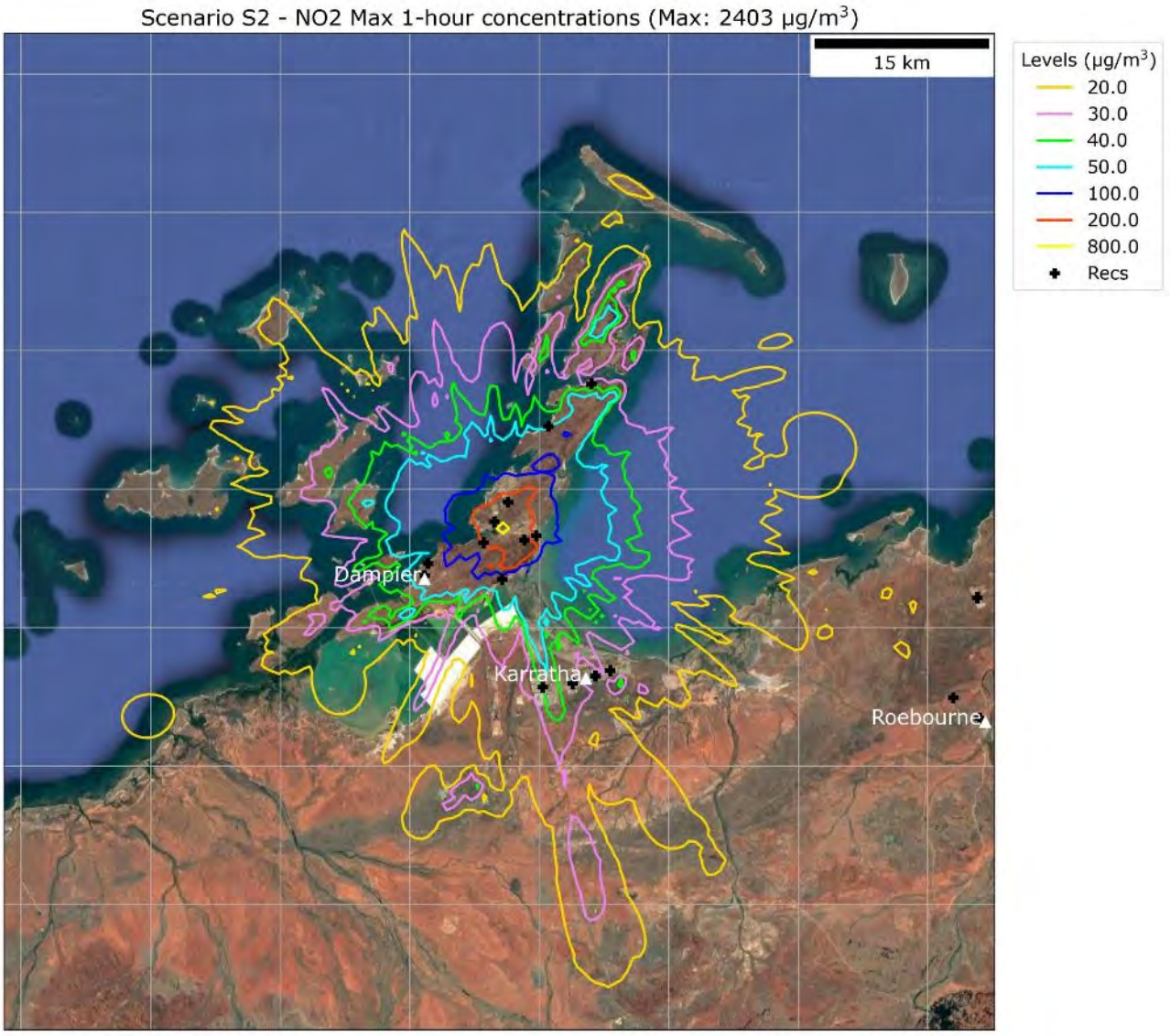

Figure 43. Contour levels of the maximum 1-hour concentrations of NO_2. Scenario S2.

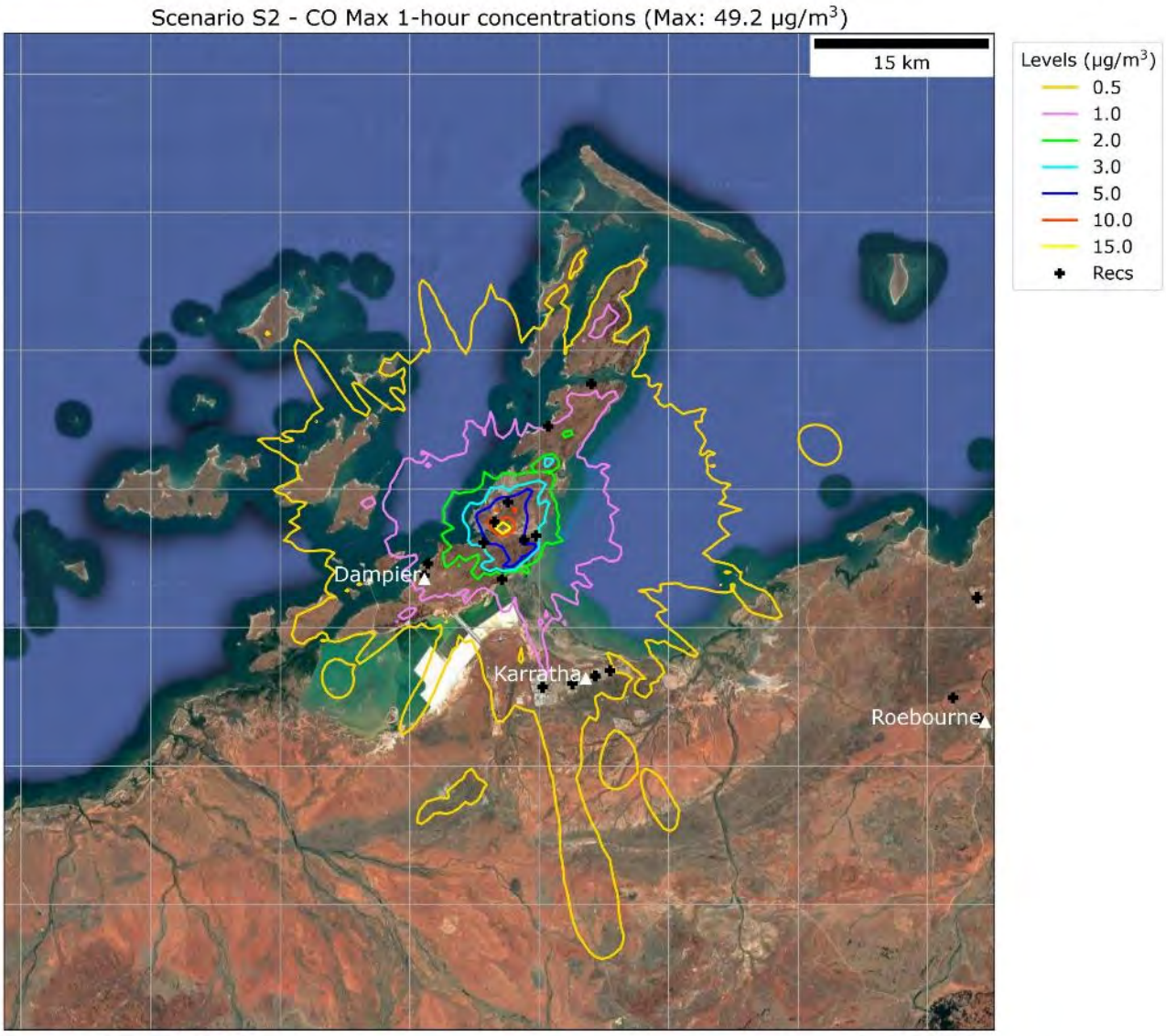

Figure 44. Contour levels of the maximum 1-hour concentrations of CO. Scenario S2.

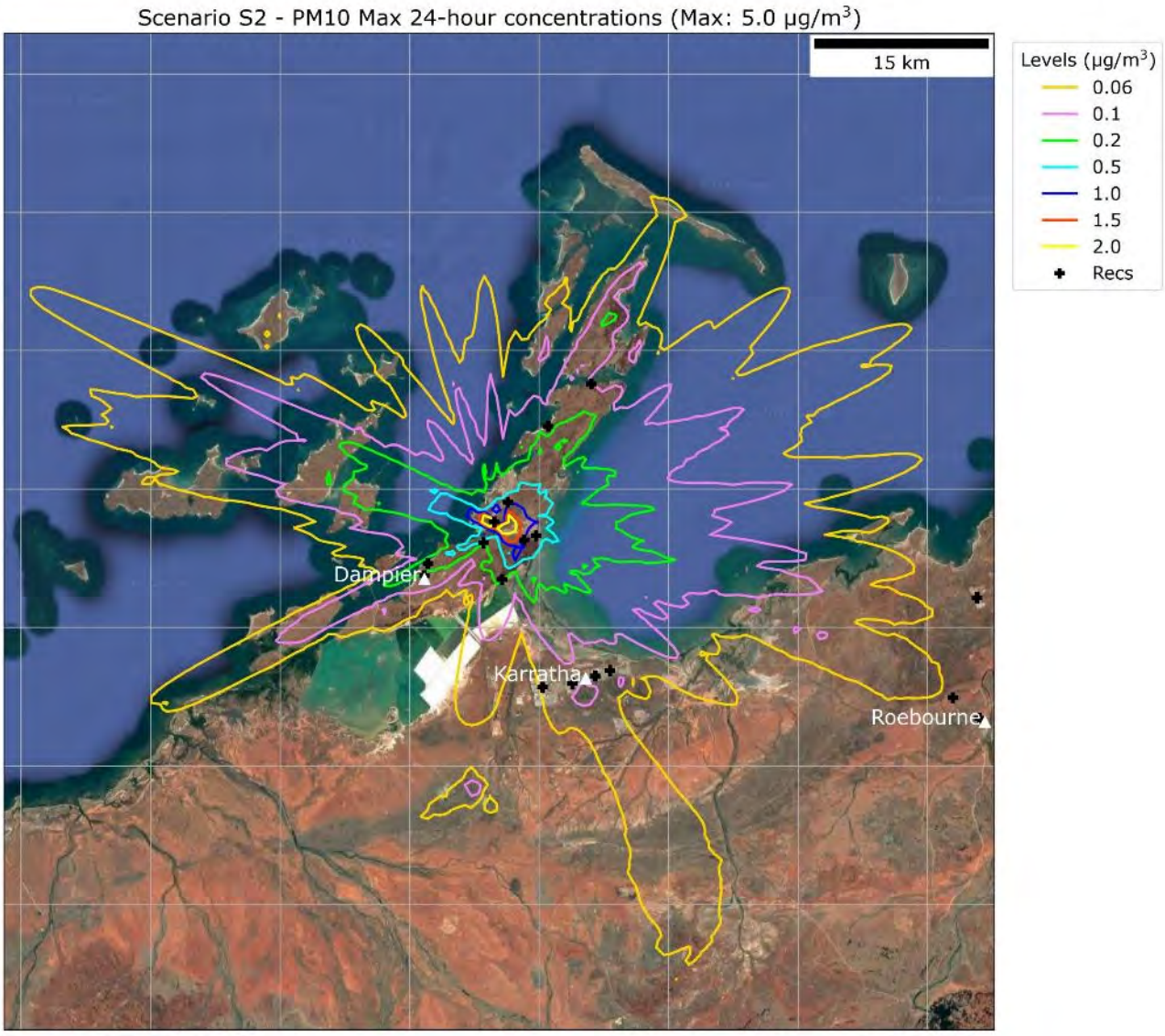

Figure 45. Contour levels of the maximum 24-hour concentrations of PM10. Scenario S2.

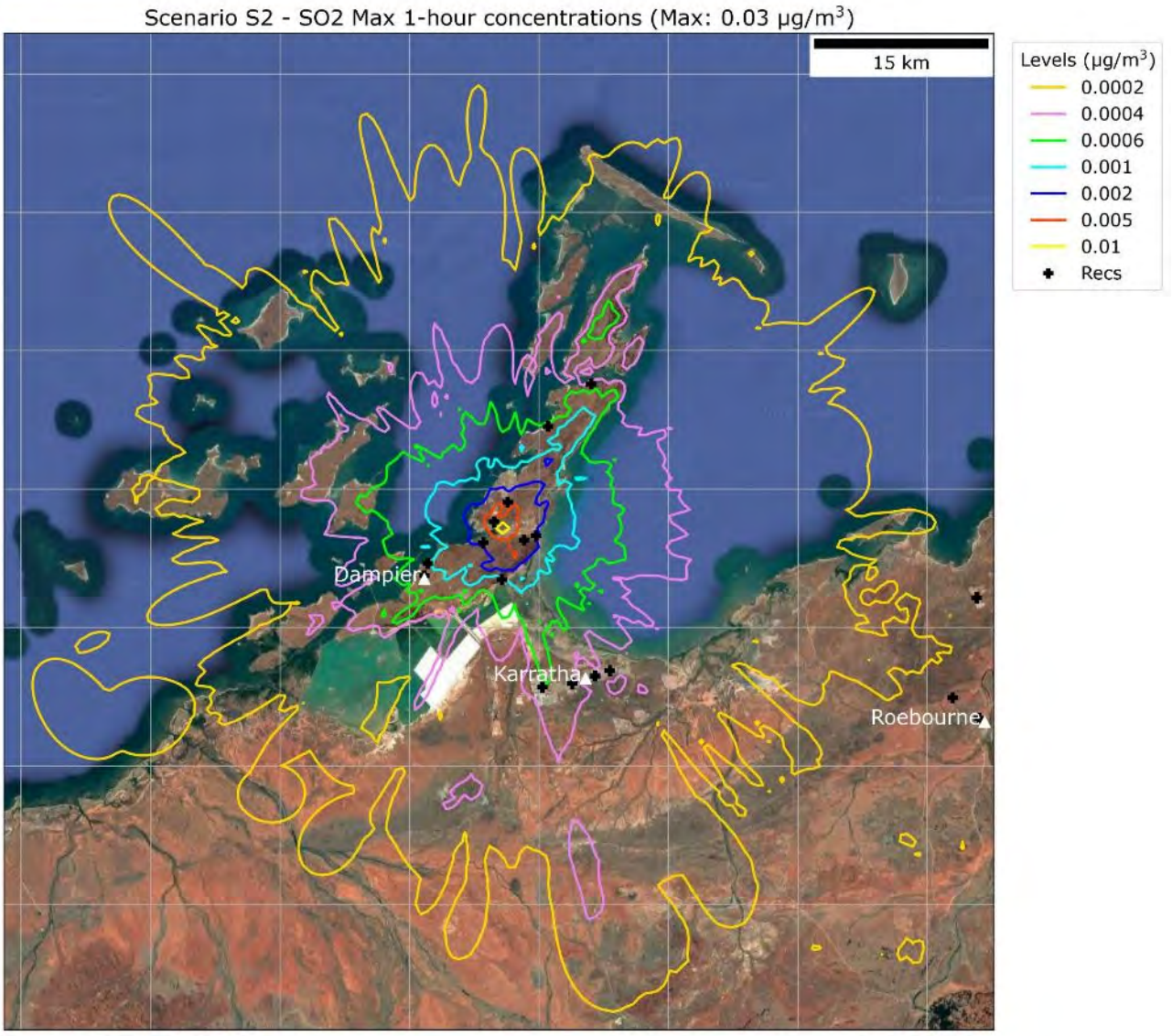

Figure 46. Contour levels of the maximum 1-hour concentrations of SO_2. Scenario S2.

9.11 SIMULTANEOUS FLARING - SCENARIO A

This scenario represents the simultaneous flaring due to FE Start Up (Syngas flare) and Ammonia BOG compressor blocked outlet (Ammonia Storage flare), as described in Table 5. The estimated frequency of the first event is 0-5 times per year with a duration less than 1 day, while the one of the second event is 1 time per 10 years with a duration less than 1 hour.
Accordingly, simultaneous scenario frequency can be expected 1 time per 10 years and its duration 1 hour.
The maximum concentrations calculated over the Cartesian receptors are summarised in Table 23, while those estimated at the sensitive receptors are reported in Table 24. All predicted concentrations are below the corresponding reference values.
The GLCs of the pollutants are represented from Figure 47 to Figure 50.

Table 23. Maximum concentrations over the Cartesian receptors. Scenario A.

Pollutant	Statistics	E (m)	N (m)	Value (µg/m^3)	ERPG-2 (µg/m^3)	Value/ERPG-2 (%)
NO_2	Max 1h	476250	7718950	2403	28211	8.52
CO	Max 1h	476750	7718450	153.6	400731	0.04
PM10	Max 24h	475250	7719450	4.6	50	9.21
SO_2	Max 1h	476250	7718950	0.03	7857	0.0004

Table 24. Maximum concentrations at the sensitive receptors. Scenario A.

Receptor	NO_2 Max 1h (µg/m^3)	CO Max 1h (µg/m^3)	PM10 Max 24h (µg/m^3)	SO_2 Max 1h (µg/m^3)
R1	323.0	12.2	0.93	0.0043
R2	70.8	13.0	0.49	0.0009
R3	24.2	10.5	0.36	0.0003
R4	212.7	60.8	1.70	0.0028
R5	185.6	34.7	1.26	0.0024
R6	35.2	7.3	0.20	0.0005
R7	74.2	22.6	1.04	0.0010
R8	695.5	19.9	5.03	0.0092
R9	195.4	31.0	0.56	0.0026
R10	48.0	12.6	0.27	0.0006
R11	64.2	11.4	0.43	0.0008
R12	41.6	11.0	0.38	0.0005
R13	32.2	9.0	0.43	0.0004
R14	26.0	9.1	0.35	0.0003
R15	8.5	2.7	0.10	0.0001
R16	7.9	2.6	0.15	0.0001
R17	10.7	3.6	0.23	0.0001

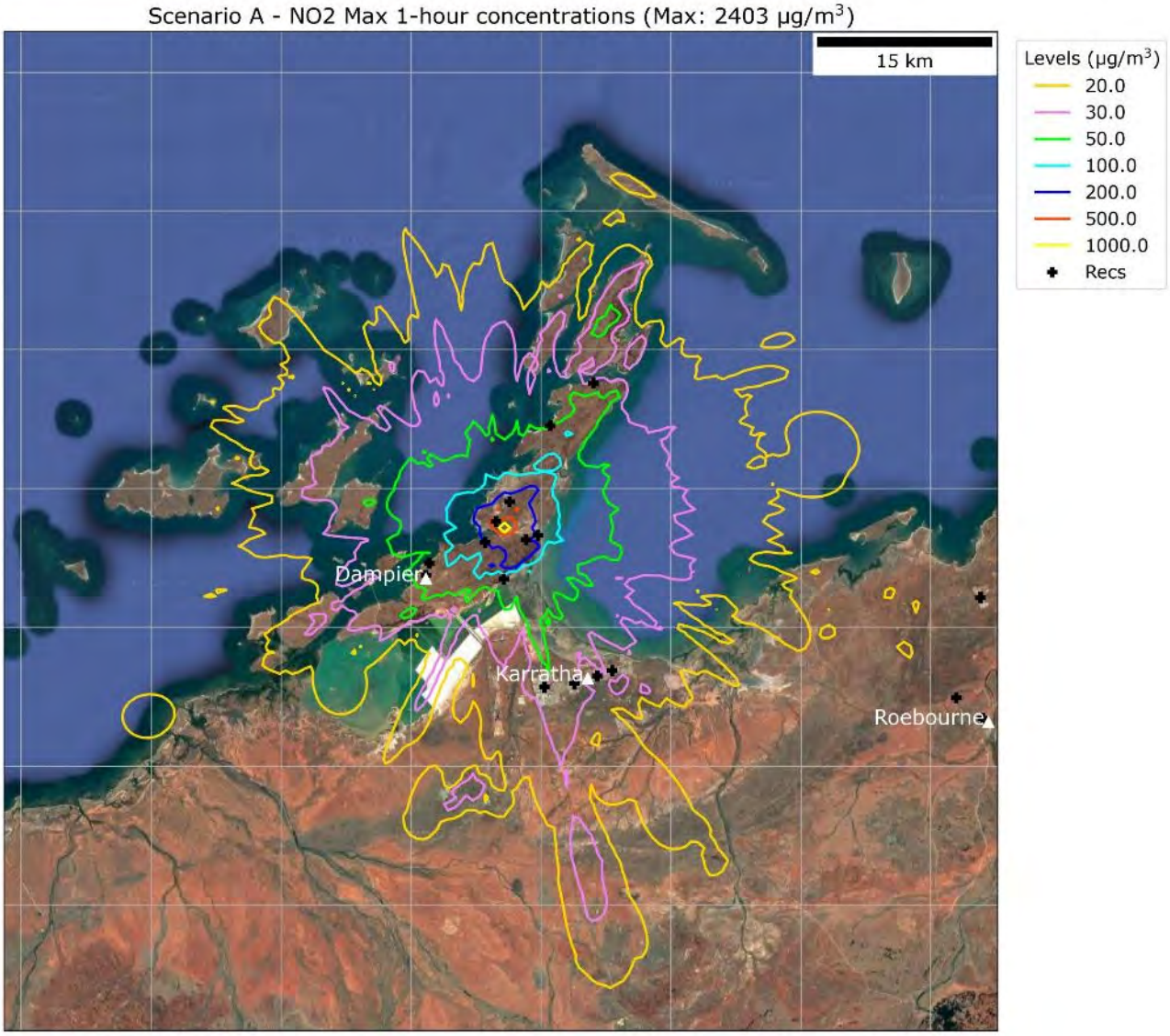

Figure 47. Contour levels of the maximum 1-hour concentrations of NO_2. Scenario A.

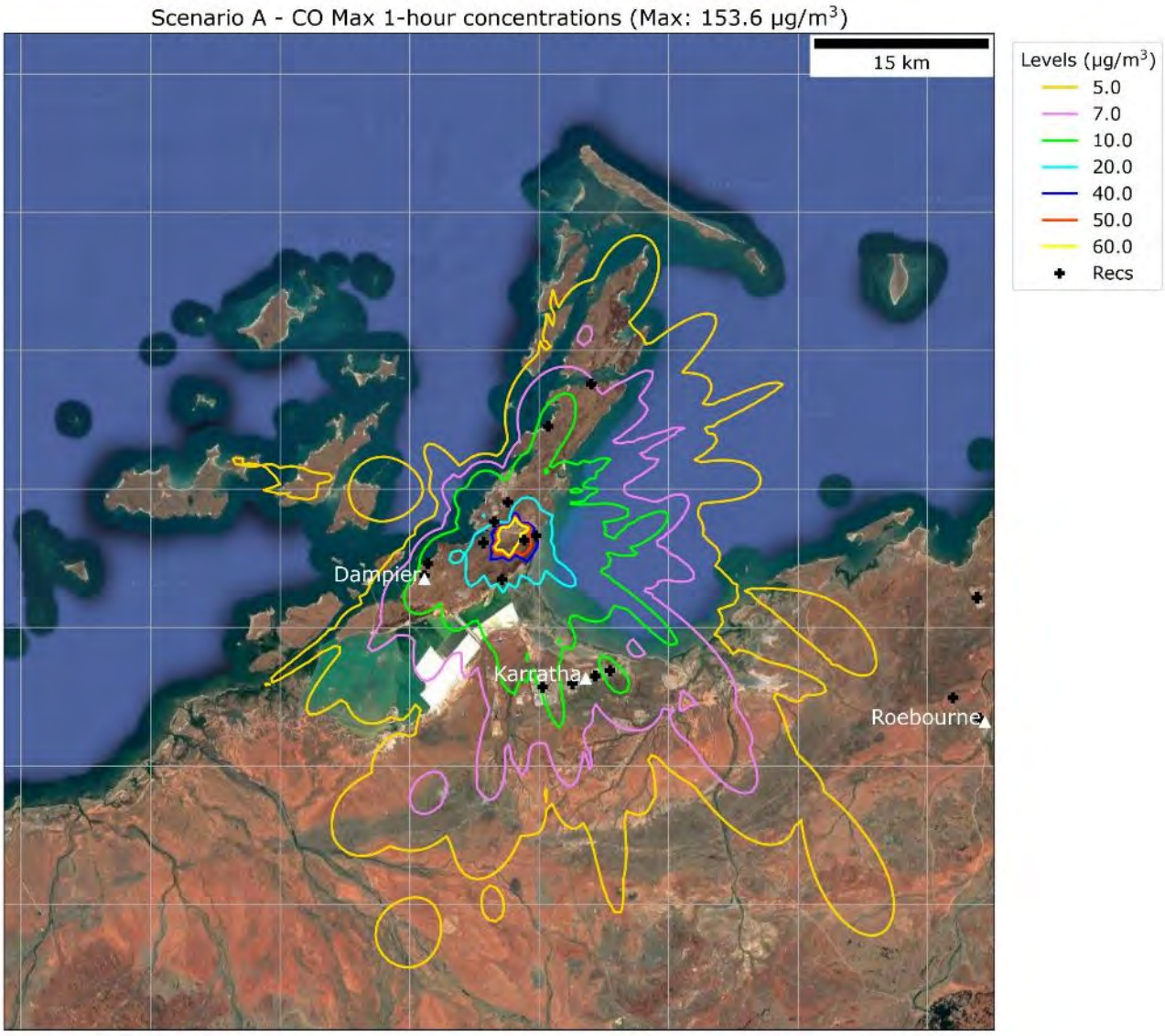

Figure 48. Contour levels of the maximum 1-hour concentrations of CO. Scenario A.

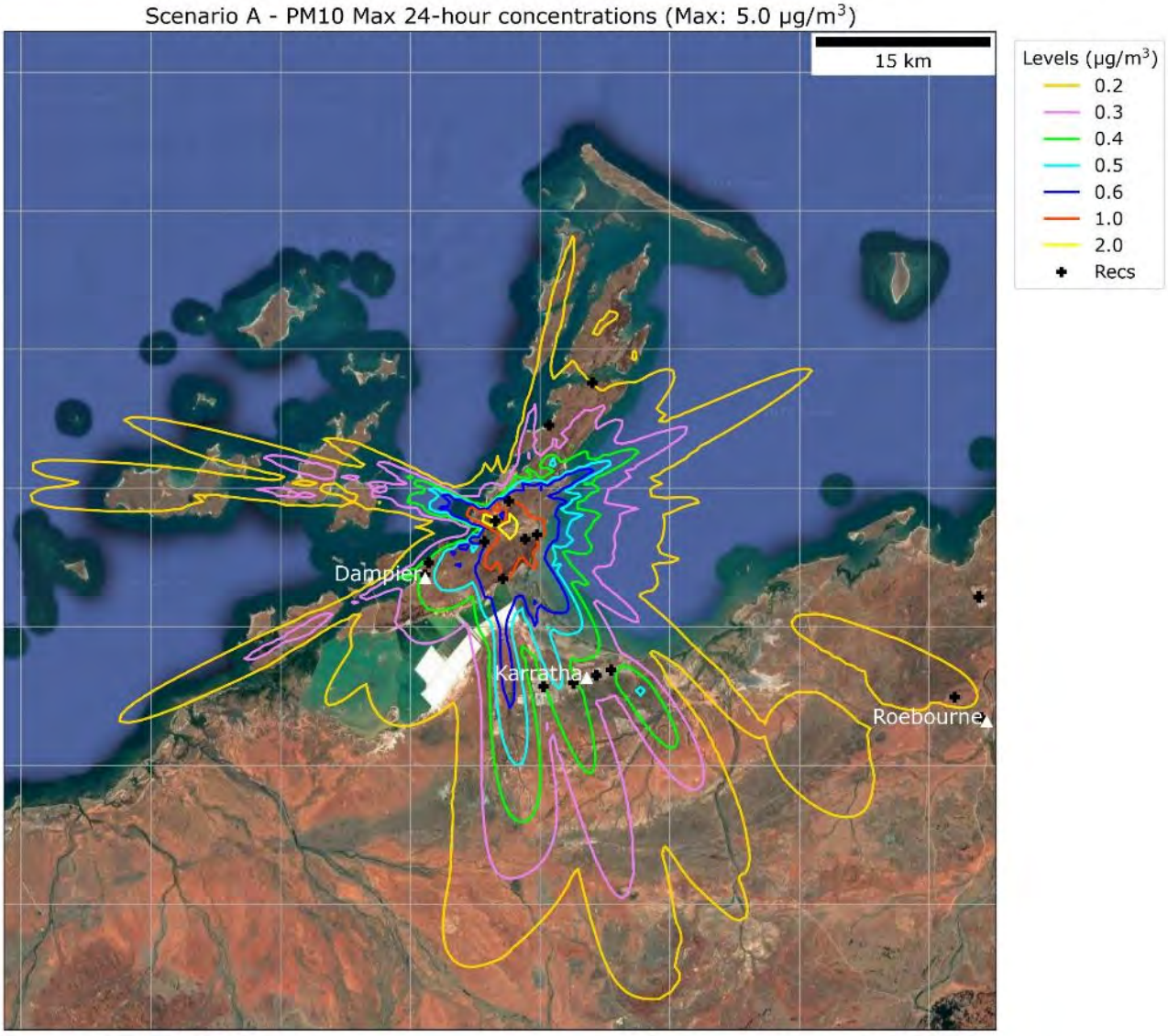

Figure 49. Contour levels of the maximum 24-hour concentrations of PM10. Scenario A.

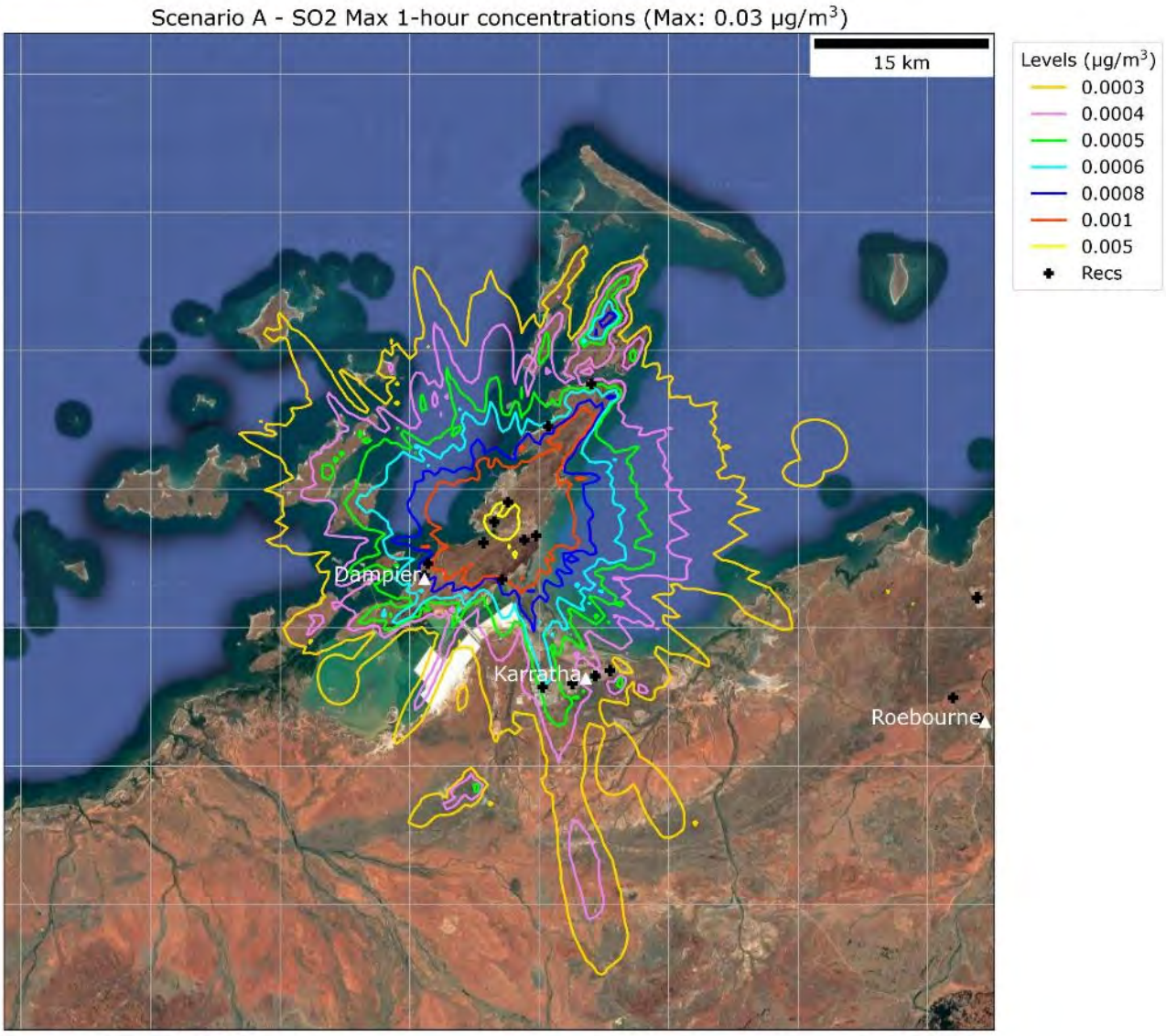

Figure 50. Contour levels of the maximum 1-hour concentrations of SO_2. Scenario A.

9.12 SIMULTANEOUS FLARING - SCENARIO B

This scenario represents the simultaneous flaring due to 2500-K-431 Syngas compressor trip (Ammonia flare) and Trip of CO2 Removal gas (Syngas flare), as described in Table 5. The estimated frequency of the first event is 0-5 times per year with a duration less than 1 minute, while the one of the second event is 0-5 times per year with a duration less than 1 day. Accordingly, simultaneous scenario frequency can be expected 0-5 times per year and its duration less than 1 minute.
The maximum concentrations calculated over the Cartesian receptors are summarised in Table 25, while those estimated at the sensitive receptors are reported in Table 26. All predicted concentrations are below the corresponding reference values.
The GLCs of the pollutants are represented from Figure 51 to Figure 53.

Table 25. Maximum concentrations over the Cartesian receptors. Scenario B.

Pollutant	Statistics	E (m)	N (m)	Value (µg/m³)	ERPG-2 (µg/m³)	Value/ERPG-2 (%)
NO_2	Max 1h	476750	7718450	31.6	28211	0.11
CO	Max 1h	476750	7718450	144.0	400731	0.04
PM10	Max 24h	473750	7719950	25.1	50	50.25
SO_2	Max 1h	-	-	-	7857	-

Table 26. Maximum concentrations at the sensitive receptors. Scenario B.

Receptor	NO_2 Max 1h (µg/m³)	CO Max 1h (µg/m³)	PM10 Max 24h (µg/m³)	SO_2 Max 1h (µg/m³)
R1	2.9	13.2	11.6	-
R2	2.7	12.1	4.7	-
R3	2.2	10.0	4.5	-
R4	11.7	53.2	12.5	-
R5	7.4	33.7	13.2	-
R6	1.9	8.7	1.6	-
R7	4.9	22.4	8.1	-
R8	5.8	26.6	6.4	-
R9	7.2	32.6	7.3	-
R10	1.9	8.7	2.8	-
R11	2.6	12.1	3.0	-
R12	1.9	8.7	3.9	-
R13	1.8	8.1	4.6	-
R14	1.8	8.2	3.4	-
R15	0.6	2.6	0.9	-
R16	0.5	2.5	1.5	-
R17	0.7	3.2	2.0	-

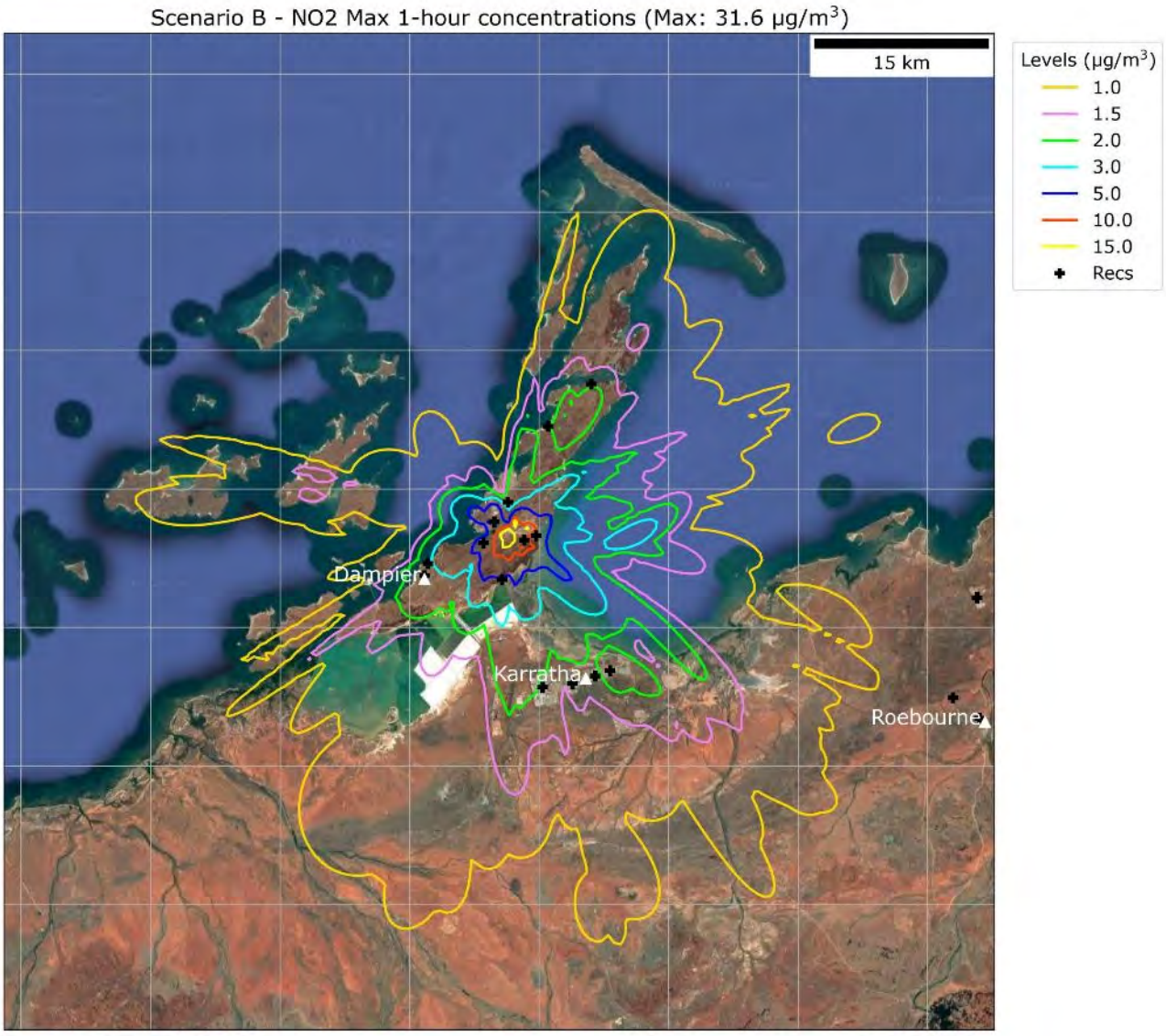

Figure 51. Contour levels of the maximum 1-hour concentrations of NO_2. Scenario B.

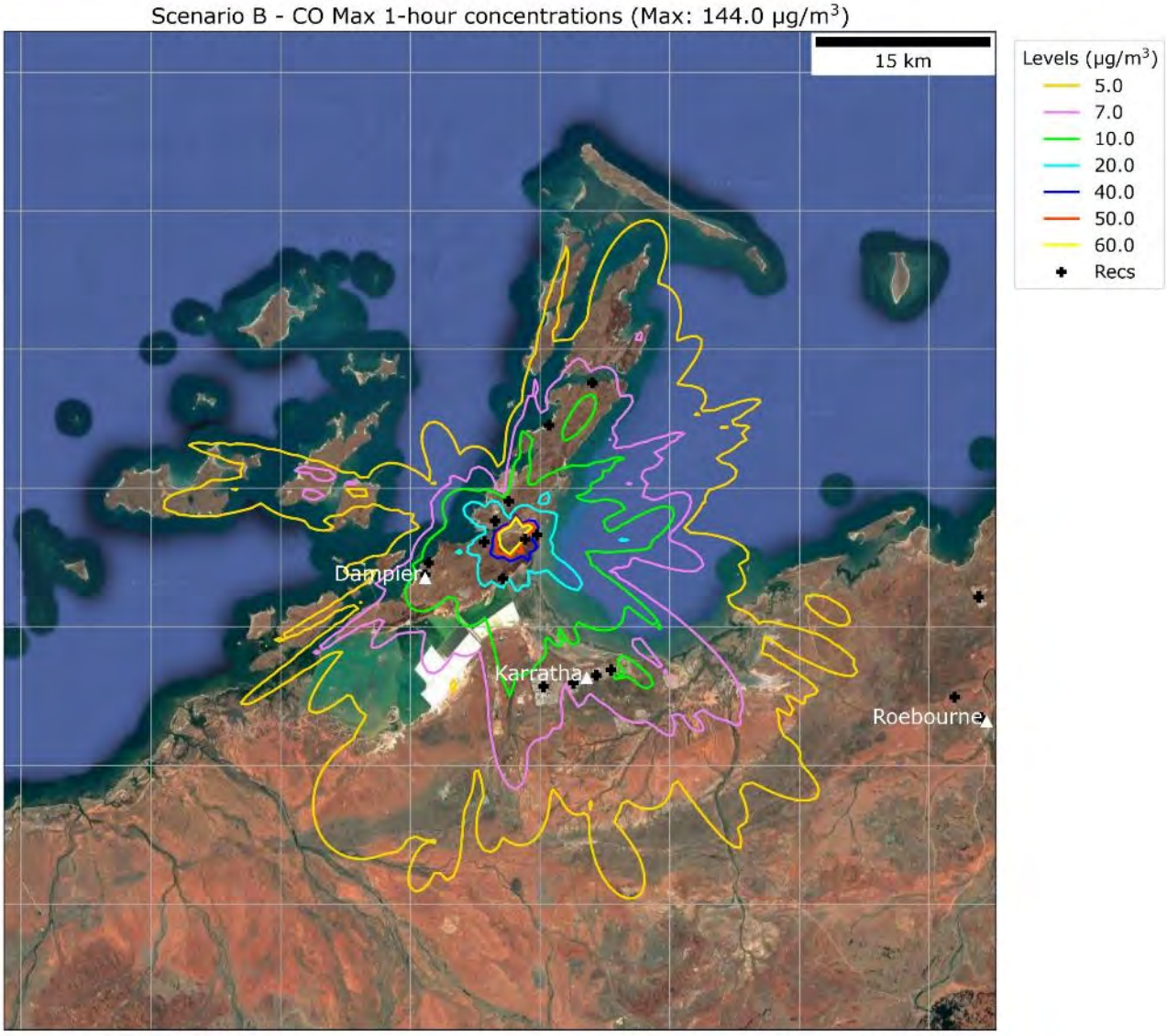

Figure 52. Contour levels of the maximum 1-hour concentrations of CO. Scenario B.

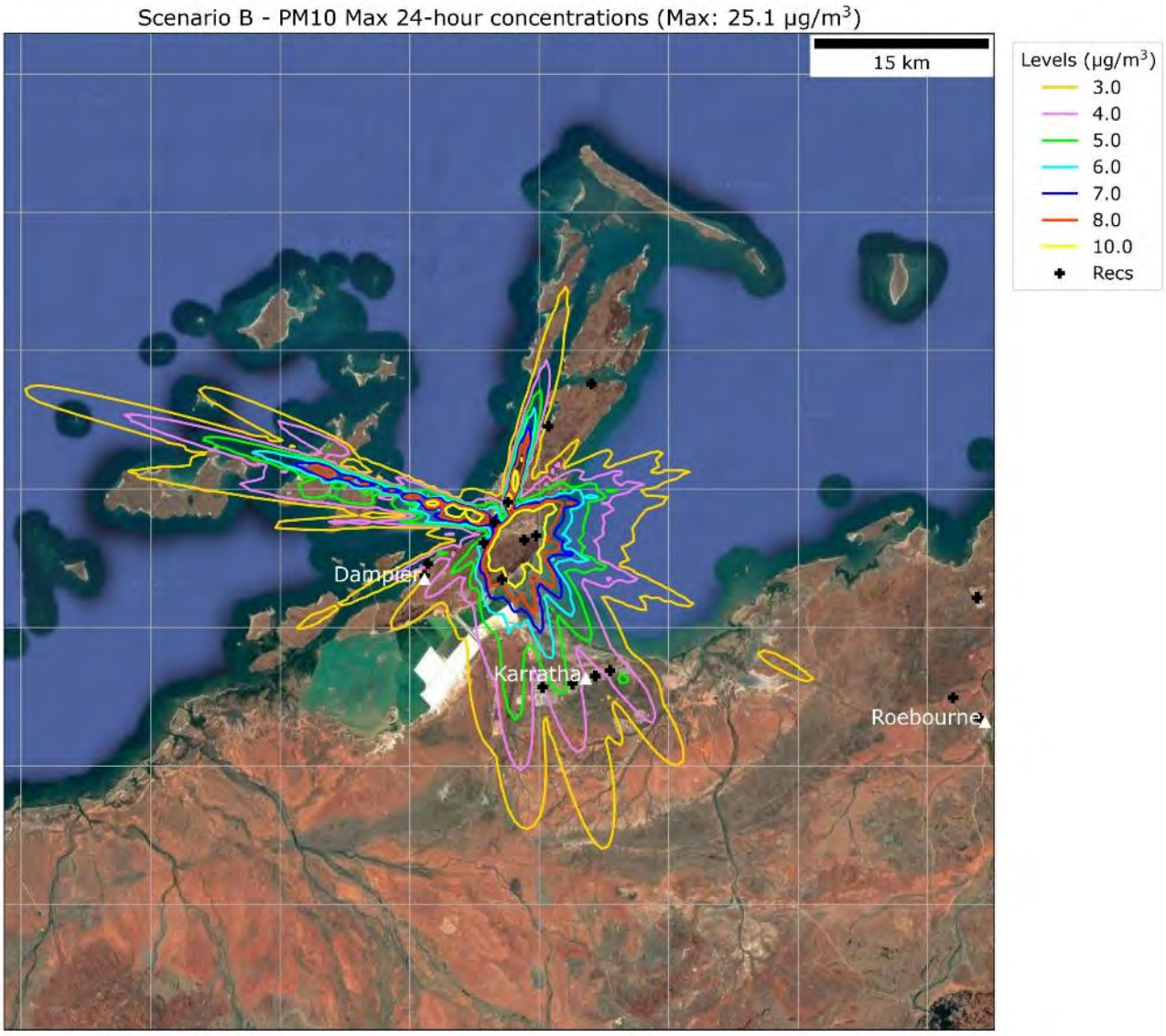

Figure 53. Contour levels of the maximum 24-hour concentrations of PM10. Scenario B.

9.13 SIMULTANEOUS FLARING SCENARIO CA

This scenario represents the simultaneous flaring due to Granulation unit in shut-down (Primary Urea Flare) and 2500-K-441 Discharge blocked outlet (Ammonia flare), as described in Table 5. The estimated frequency of the first event is once every 30 days with a duration of 8 hours, while the one of the second event is 1 time per 10 years with a duration less than 1 hour. Accordingly, simultaneous scenario frequency can be expected 1 time per ten years and its duration less than 1 hour.
The maximum concentrations calculated over the Cartesian receptors are summarised in Table 27, while those estimated at the sensitive receptors are reported in Table 28. All predicted concentrations are below the corresponding reference values.
The GLCs of the pollutants are represented from Figure 54 to Figure 57.

Table 27. Maximum concentrations over the Cartesian receptors. Scenario Ca.

Pollutant	Statistics	E (m)	N (m)	Value (µg/m³)	ERPG-2 (µg/m³)	Value/ERPG-2 (%)
NO_2	Max 1h	476250	7718950	3797	28211	13.46
CO	Max 1h	476750	7718450	78.6	400731	0.02
PM10	Max 24h	475250	7719450	6.1	50	12.28
SO_2	Max 1h	476250	7718950	0.32	7857	0.004

Table 28. Maximum concentrations at the sensitive receptors. Scenario Ca.

Receptor	NO_2 Max 1h (µg/m³)	CO Max 1h (µg/m³)	PM10 Max 24h (µg/m³)	SO_2 Max 1h (µg/m³)
R1	569.7	11.3	1.2	0.110
R2	494.0	9.8	1.0	0.032
R3	311.7	6.2	1.0	0.012
R4	2359.7	47.0	3.7	0.107
R5	1196.6	23.8	2.1	0.069
R6	325.8	6.5	0.4	0.013
R7	832.8	16.6	2.6	0.039
R8	772.6	15.4	1.6	0.191
R9	1124.6	23.4	1.1	0.093
R10	269.2	5.4	0.4	0.022
R11	419.8	8.4	0.7	0.031
R12	302.0	6.0	1.0	0.018
R13	262.9	5.2	1.0	0.017
R14	284.3	5.7	0.8	0.013
R15	94.6	1.9	0.3	0.004
R16	85.7	1.7	0.4	0.004
R17	104.8	2.1	0.5	0.005

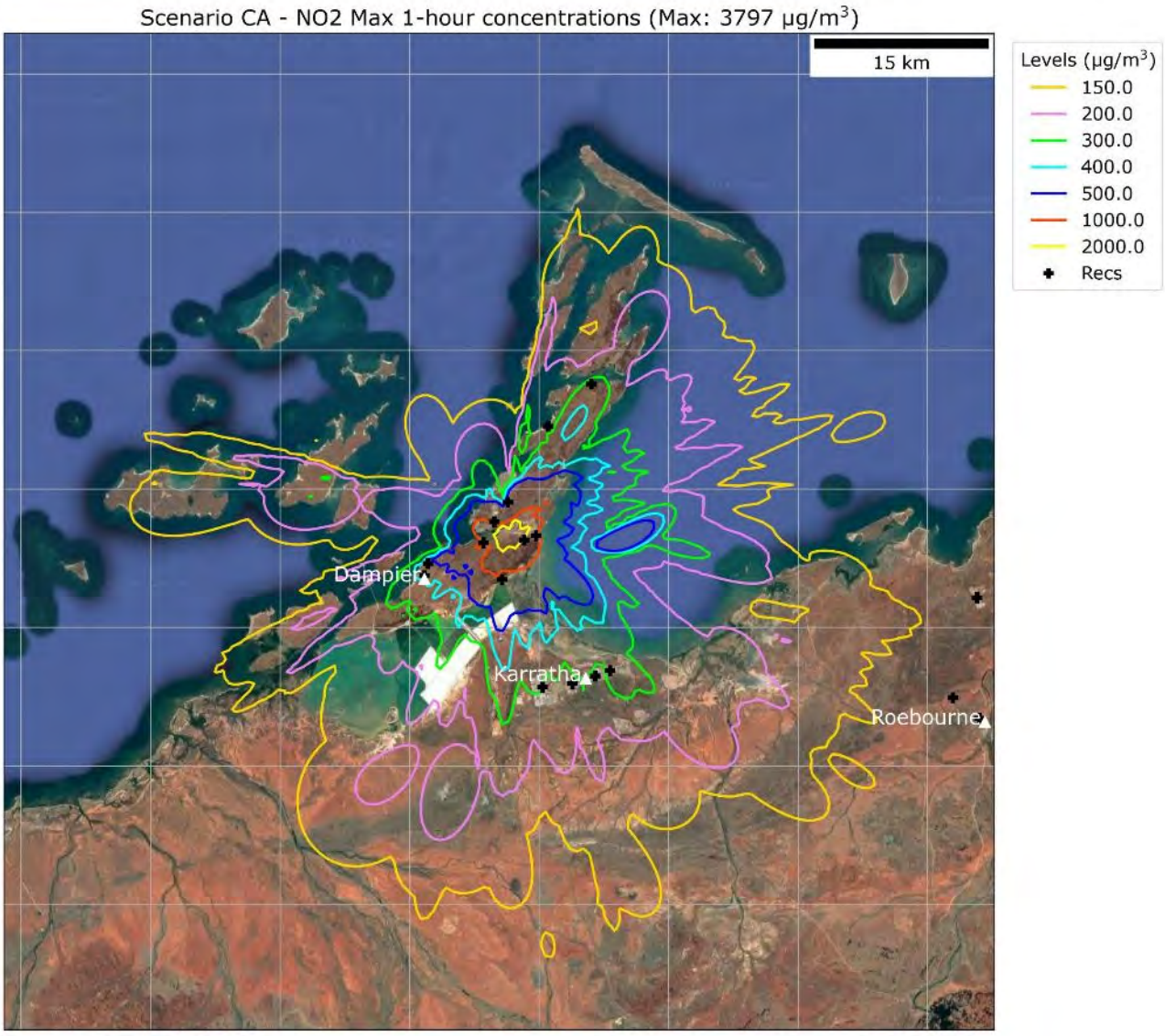

Figure 54. Contour levels of the maximum 1-hour concentrations of NO_2. Scenario Ca.

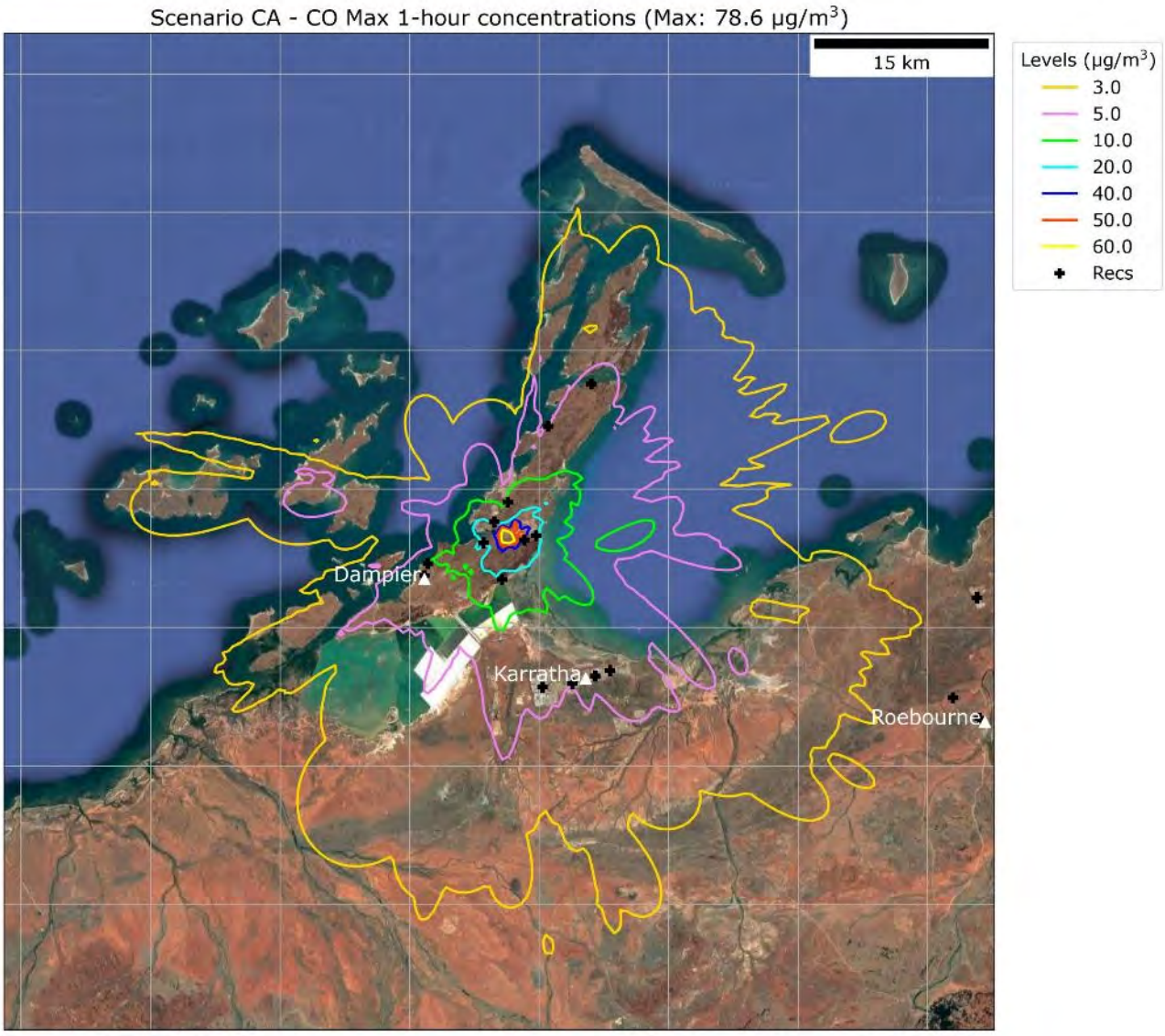

Figure 55. Contour levels of the maximum 1-hour concentrations of CO. Scenario Ca.

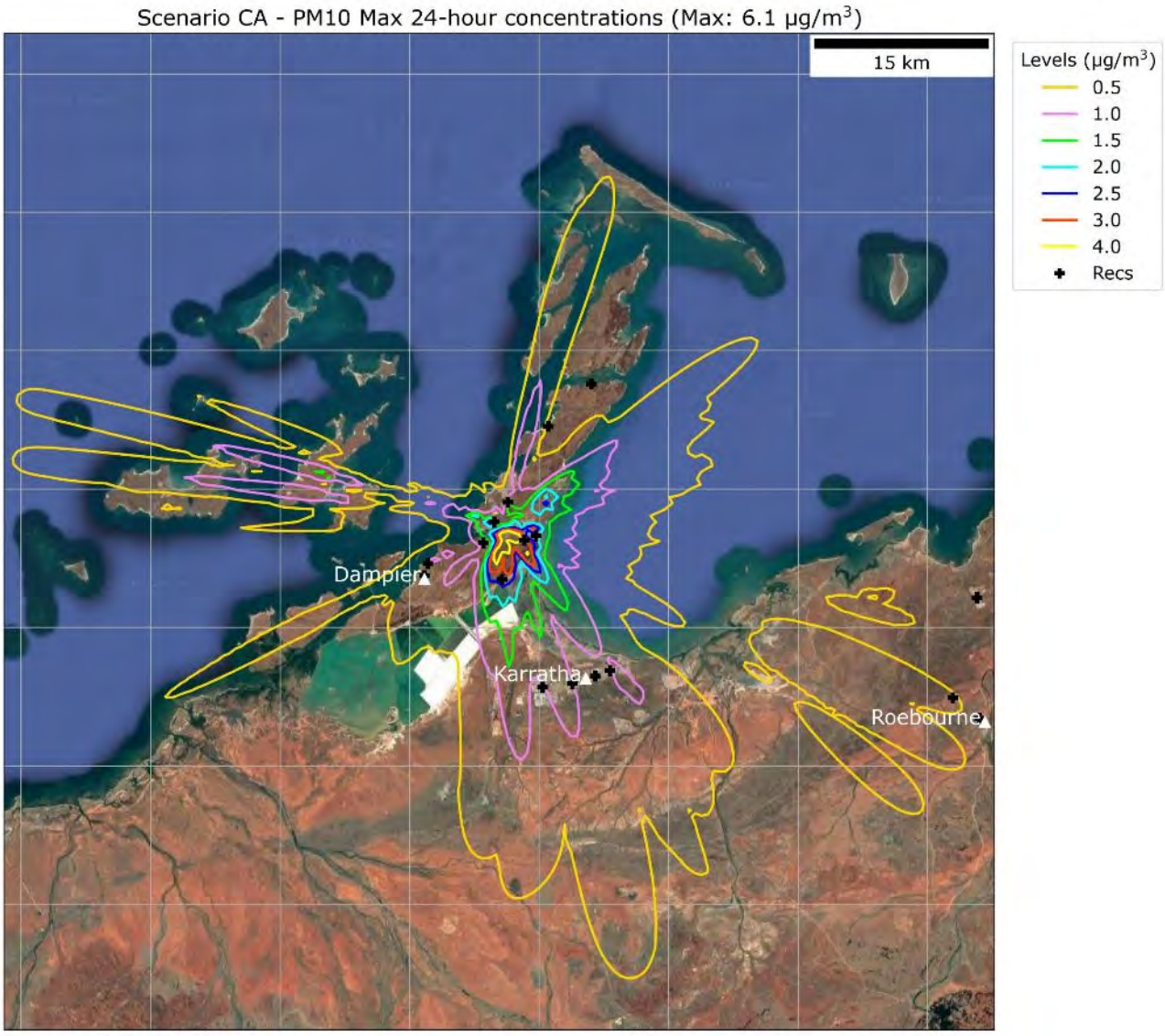

Figure 56. Contour levels of the maximum 24-hour concentrations of PM10. Scenario Ca.

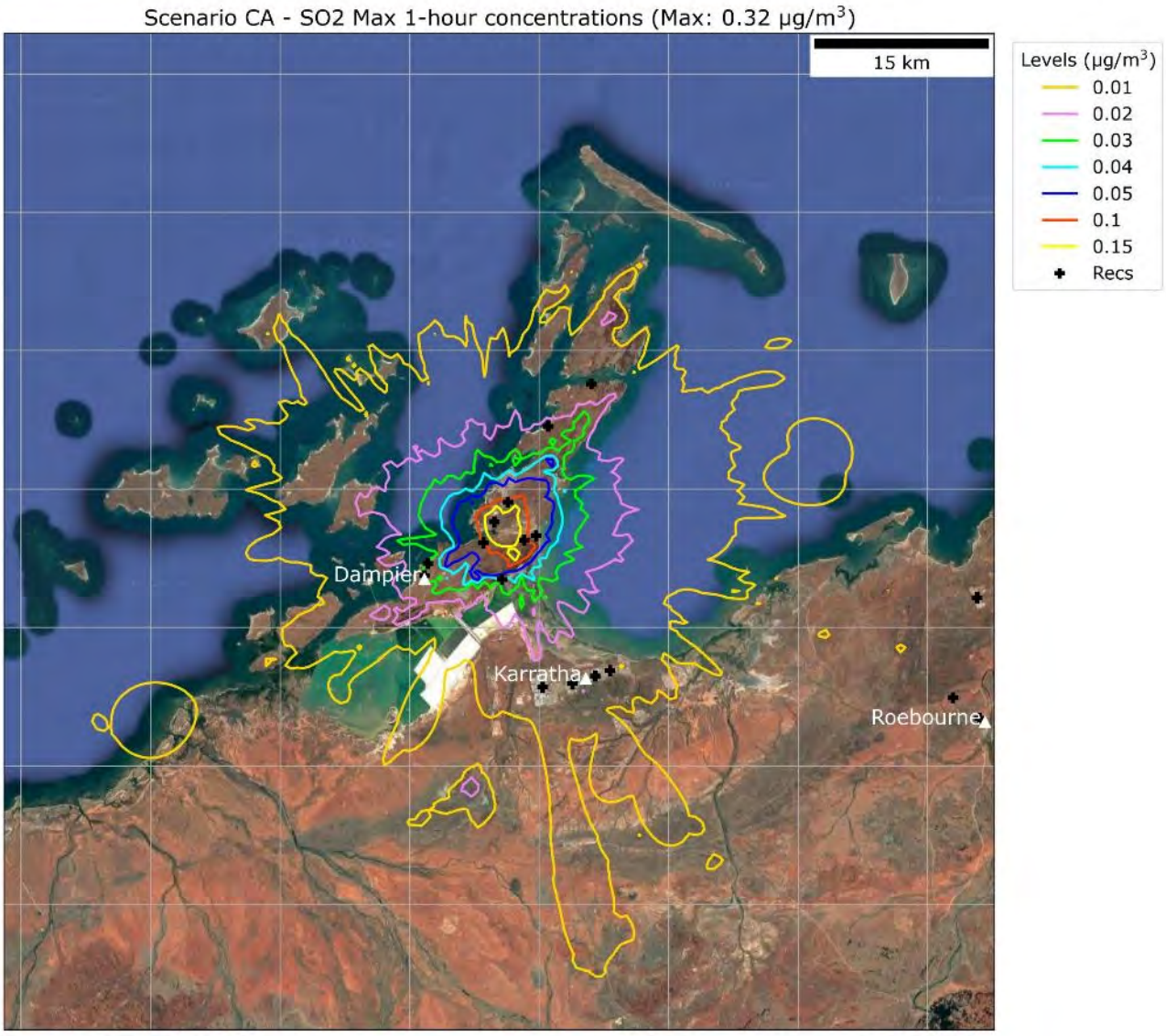

Figure 57. Contour levels of the maximum 1-hour concentrations of SO_2. Scenario Ca.

9.14 SIMULTANEOUS FLARING SCENARIO D

This scenario represents the simultaneous flaring due to HP section vent from V-101 through PV-1021B fully open (Secondary Urea Flare) and Granulation unit in shut-down (Primary Urea Flare), as described in Table 5. The occurrence of the first event is 1 time per 10 years with a duration of 10 minutes, while the estimated frequency of the second event is once every 30 days with a duration of 8 hours. Accordingly, simultaneous scenario frequency can be expected 1 time per 10 years and its duration 10 minutes.
The maximum concentrations calculated over the Cartesian receptors are summarised in Table 29, while those estimated at the sensitive receptors are reported in Table 30. All predicted concentrations are below the corresponding reference values.
The GLCs of the pollutants are represented from Figure 58 to Figure 61.

Table 29. Maximum concentrations over the Cartesian receptors. Scenario D.

Pollutant	Statistics	E (m)	N (m)	Value (µg/m^3)	ERPG-2 (µg/m^3)	Value/ERPG-2 (%)
NO_2	Max 1h	476250	7718950	2534	28211	8.98
CO	Max 1h	476250	7718950	52.3	400731	0.01
PM10	Max 24h	477250	7717950	5.5	50	11.03
SO_2	Max 1h	476750	7718950	0.32	7857	0.004

Table 30. Maximum concentrations at the sensitive receptors. Scenario D.

Receptor	NO_2 Max 1h (µg/m^3)	CO Max 1h (µg/m^3)	PM10 Max 24h (µg/m^3)	SO_2 Max 1h (µg/m^3)
R1	432.1	9.8	2.1	0.110
R2	225.2	4.8	1.0	0.032
R3	97.3	2.1	0.5	0.012
R4	627.2	14.1	2.8	0.107
R5	600.2	12.9	1.9	0.070
R6	128.8	2.8	0.3	0.013
R7	318.7	6.6	0.7	0.039
R8	780.9	16.2	0.9	0.193
R9	523.5	11.3	1.1	0.094
R10	148.4	3.2	0.4	0.022
R11	178.9	3.8	0.4	0.031
R12	81.7	1.7	0.3	0.018
R13	125.4	2.7	0.4	0.017
R14	117.6	2.5	0.3	0.013
R15	30.3	0.7	0.1	0.004
R16	23.8	0.5	0.1	0.004
R17	31.4	0.7	0.1	0.005

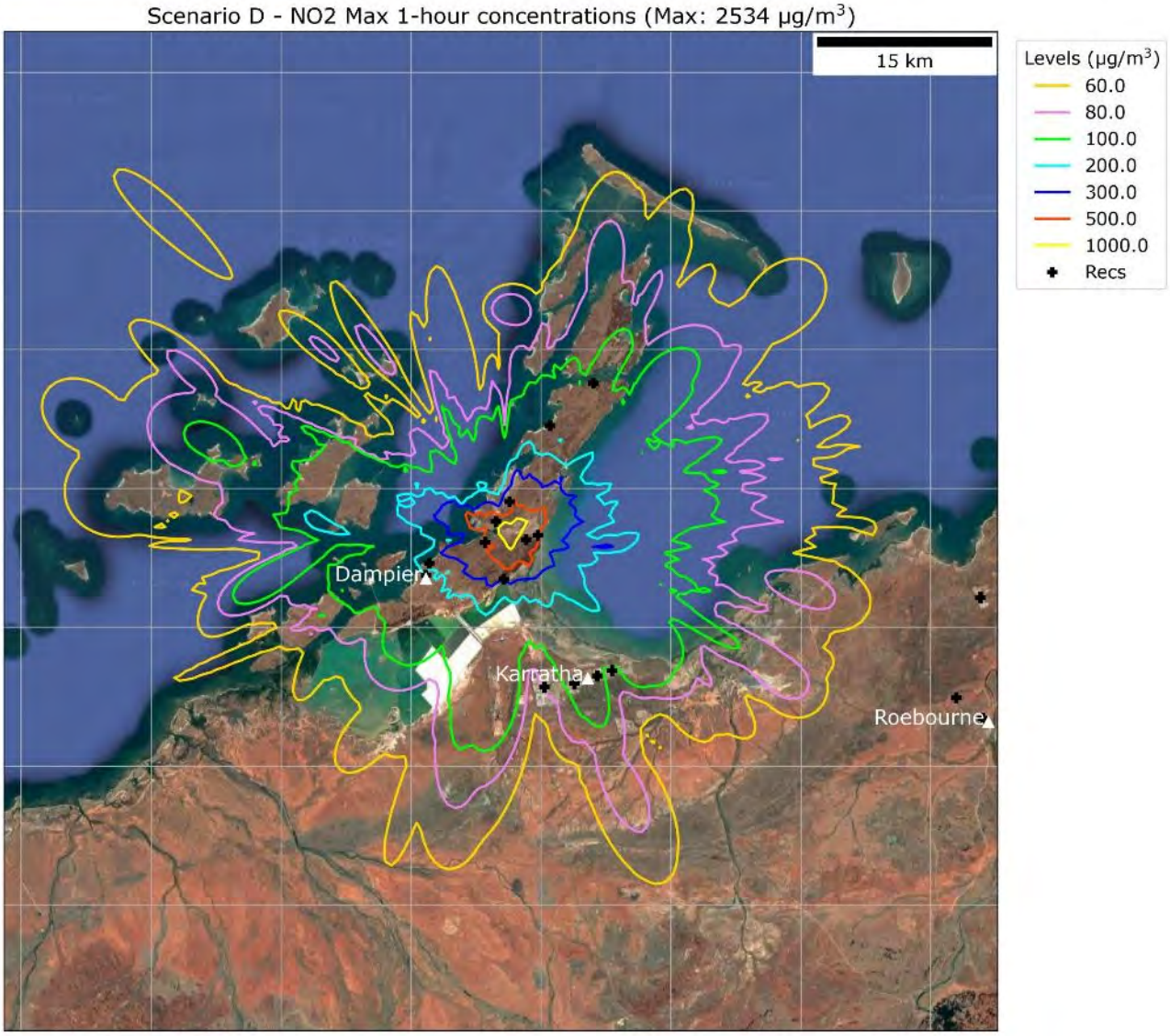

Figure 58. Contour levels of the maximum 1-hour concentrations of NO_2. Scenario D.

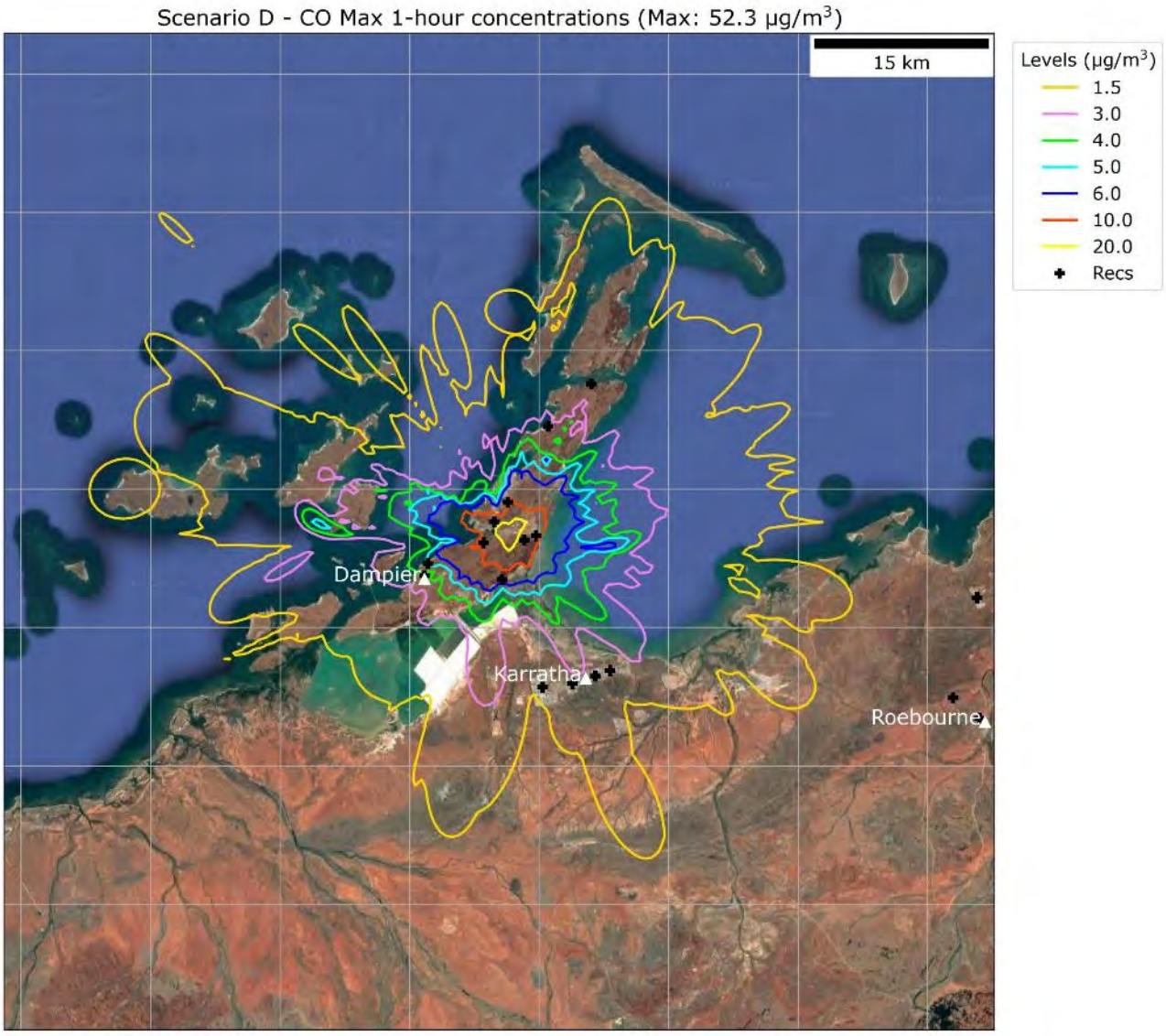

Figure 59. Contour levels of the maximum 1-hour concentrations of CO. Scenario D.

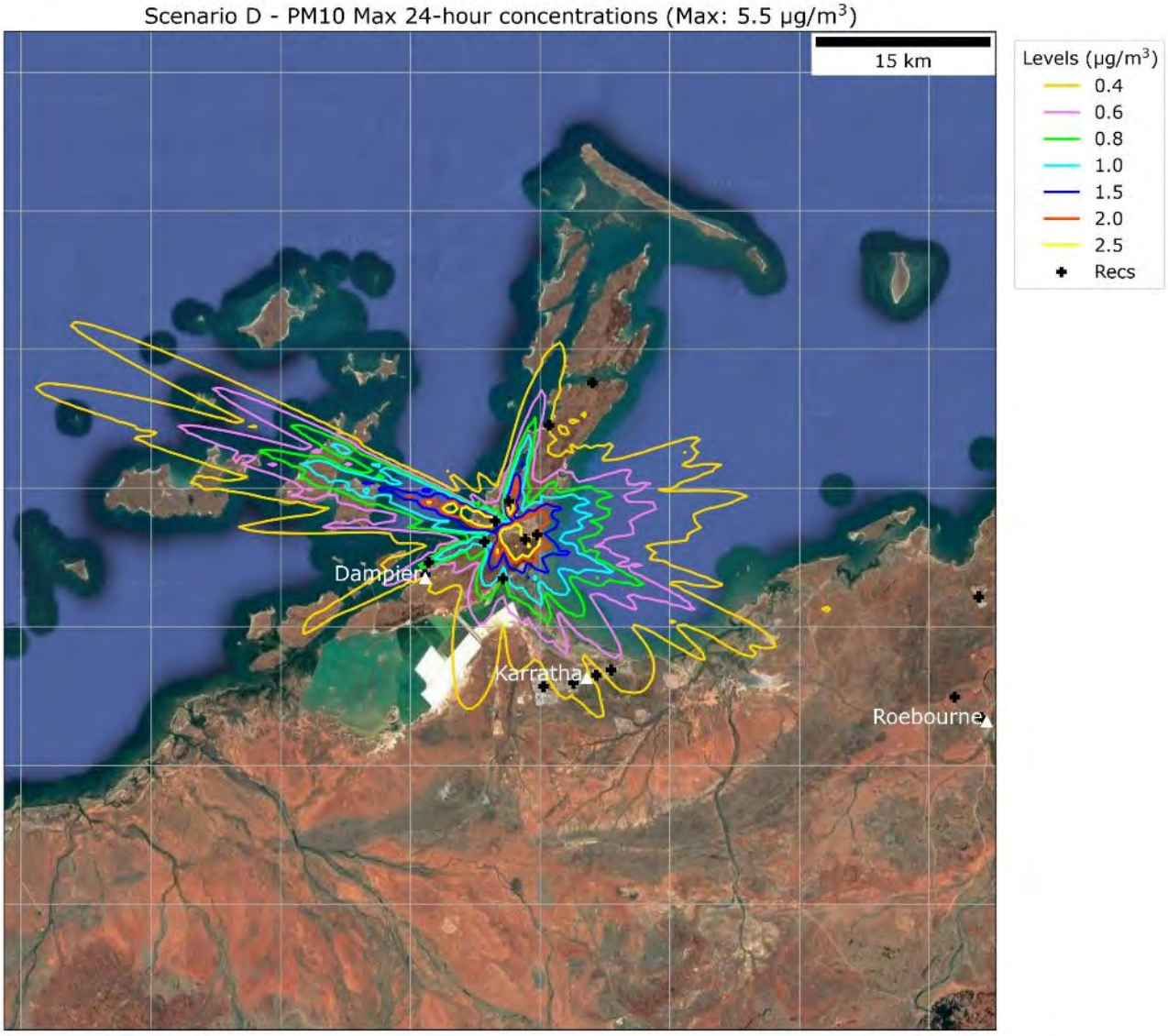

Figure 60. Contour levels of the maximum 24-hour concentrations of PM10. Scenario D.

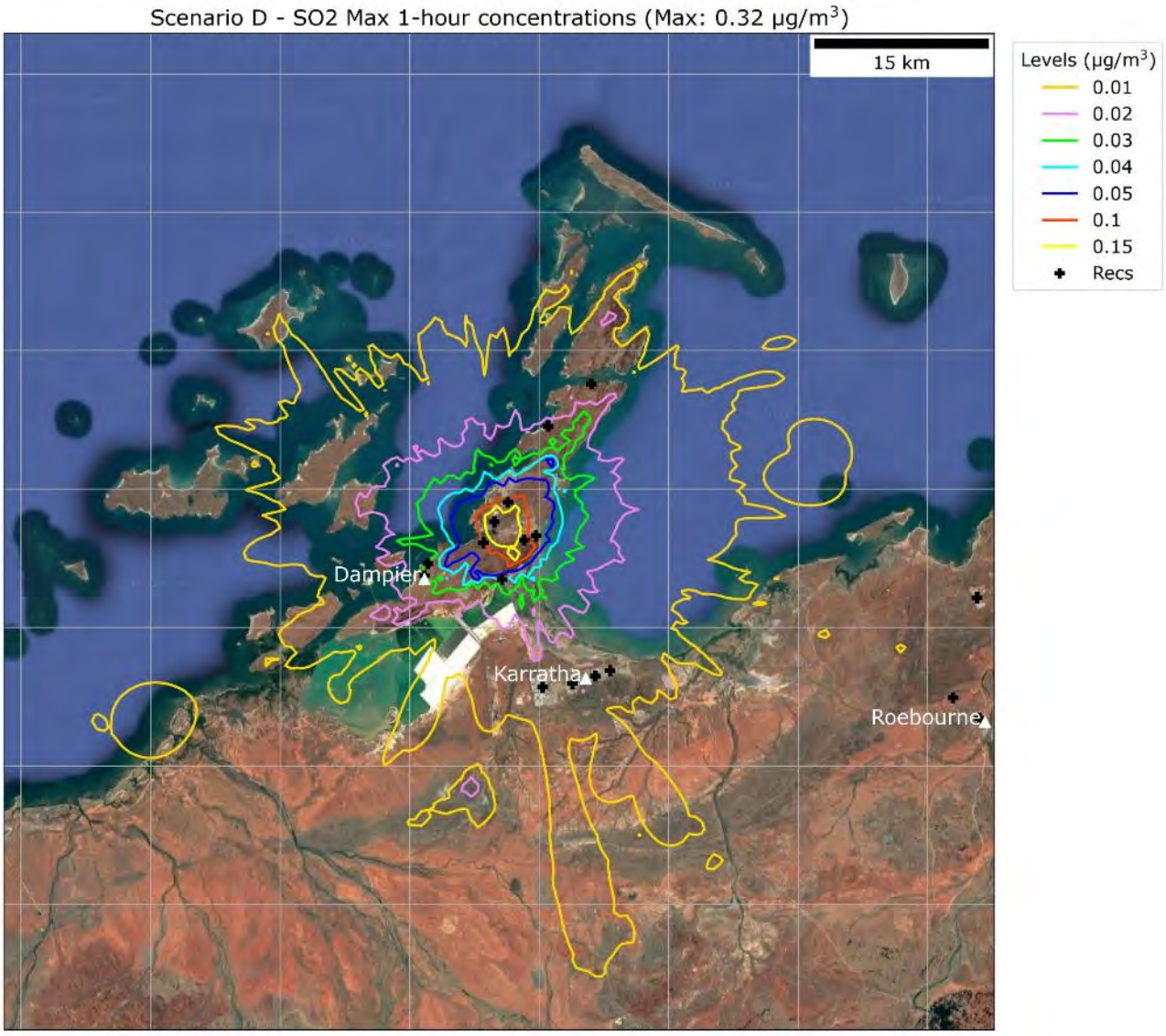

Figure 61. Contour levels of the maximum 1-hour concentrations of SO_2. Scenario D.

9.15 SIMULTANEOUS FLARING SCENARIO EA

This scenario represents the simultaneous flaring due to Granulation unit in shut-down (Primary Urea Flare) and MP section instability during start-up (Secondary Urea Flare), as described in Table 5. The estimated frequency of the first event is once every 30 days with a duration of 8 hours, while the second event has a very low frequency (0-2 times per year) and a duration of 1 hour. Accordingly, simultaneous scenario frequency can be expected 0-2 times per year and its duration 1 hour.
The maximum concentrations calculated over the Cartesian receptors are summarised in Table 31, while those estimated at the sensitive receptors are reported in Table 32. All predicted concentrations are below the corresponding reference values.
The GLCs of the pollutants are represented from Figure 62 to Figure 65.

Table 31. Maximum concentrations over the Cartesian receptors. Scenario Ea.

Pollutant	Statistics	E (m)	N (m)	Value (µg/m³)	ERPG-2 (µg/m³)	Value/ERPG-2 (%)
NO_2	Max 1h	476250	7718950	1051	28211	3.73
CO	Max 1h	476250	7718950	24.2	400731	0.01
PM10	Max 24h	475250	7719450	7.1	50	14.21
SO_2	Max 1h	476250	7718450	0.32	7857	0.004

Table 32. Maximum concentrations at the sensitive receptors. Scenario Ea.

Receptor	NO_2 Max 1h (µg/m³)	CO Max 1h (µg/m³)	PM10 Max 24h (µg/m³)	SO_2 Max 1h (µg/m³)
R1	302.6	7.6	2.2	0.110
R2	97.0	2.6	1.0	0.034
R3	33.0	0.9	0.3	0.012
R4	296.3	7.7	3.7	0.110
R5	194.8	5.2	2.2	0.073
R6	42.4	1.1	0.3	0.014
R7	122.4	3.3	0.9	0.040
R8	713.5	17.9	1.5	0.194
R9	289.1	7.1	1.1	0.097
R10	57.9	1.6	0.5	0.022
R11	54.9	1.6	0.4	0.031
R12	25.5	0.8	0.2	0.018
R13	43.1	1.1	0.3	0.018
R14	42.3	1.1	0.3	0.013
R15	14.6	0.4	0.1	0.004
R16	10.3	0.3	0.1	0.004
R17	11.5	0.3	0.2	0.005

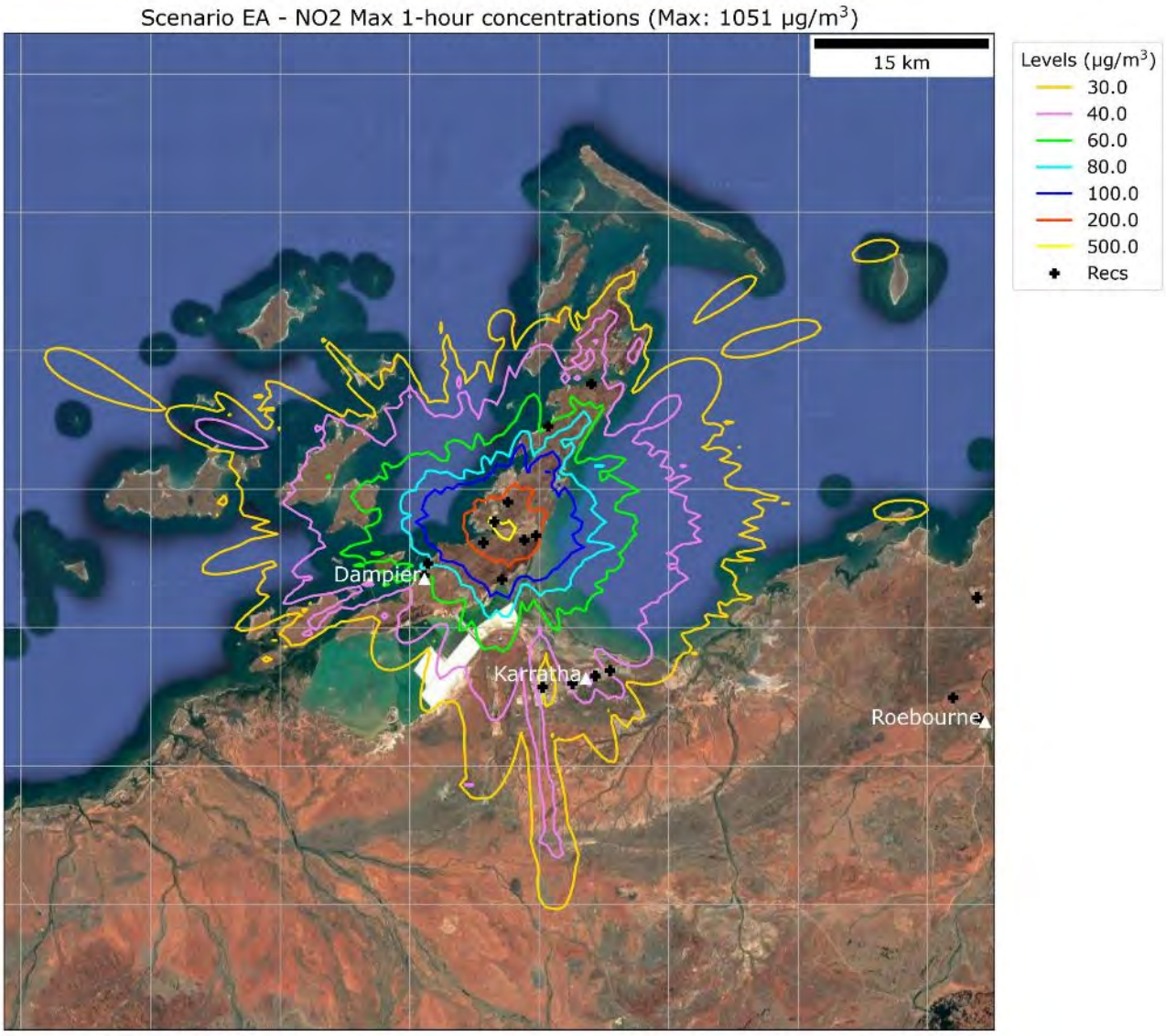

Figure 62. Contour levels of the maximum 1-hour concentrations of NO_2. Scenario Ea.

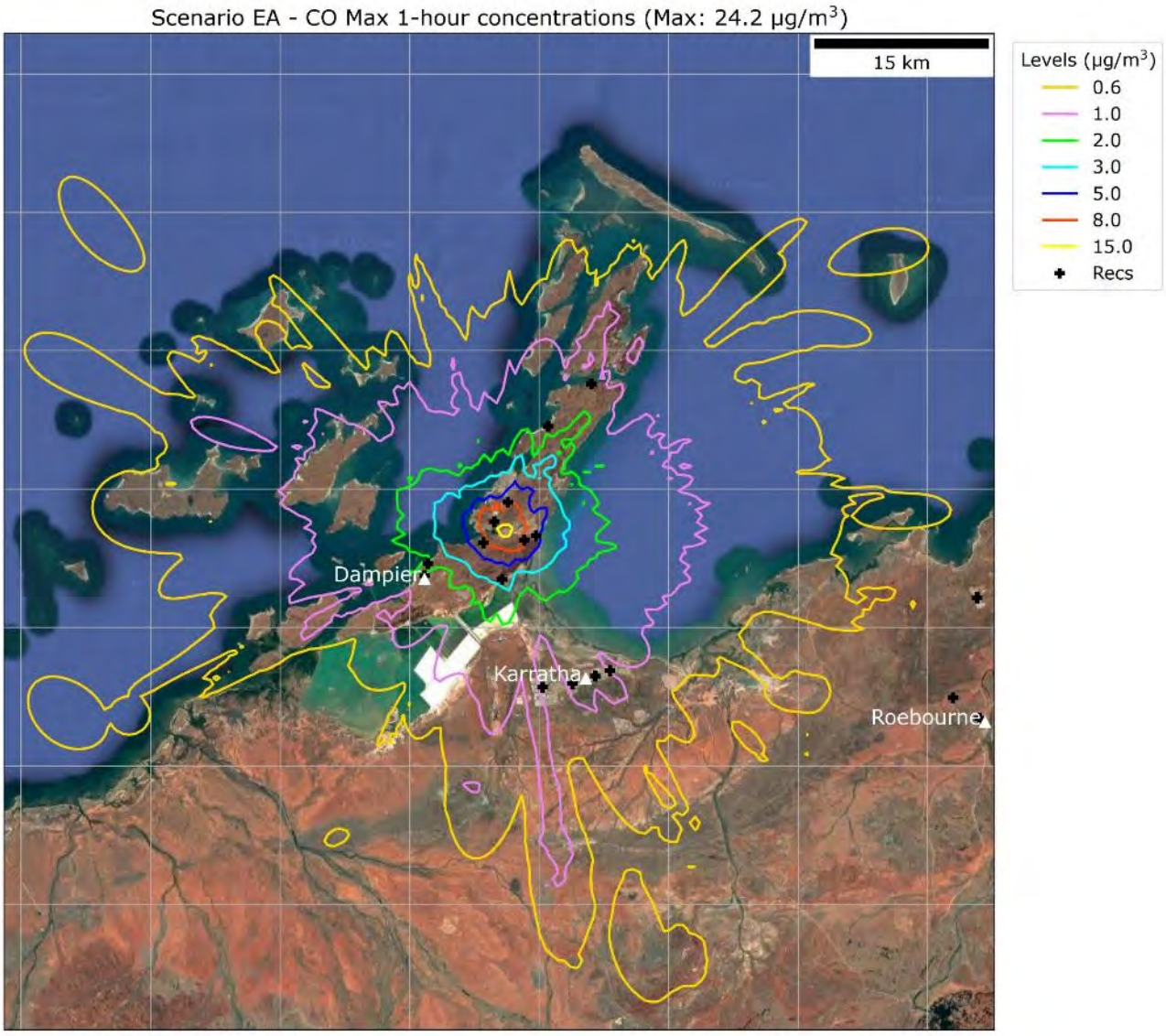

Figure 63. Contour levels of the maximum 1-hour concentrations of CO. Scenario Ea.

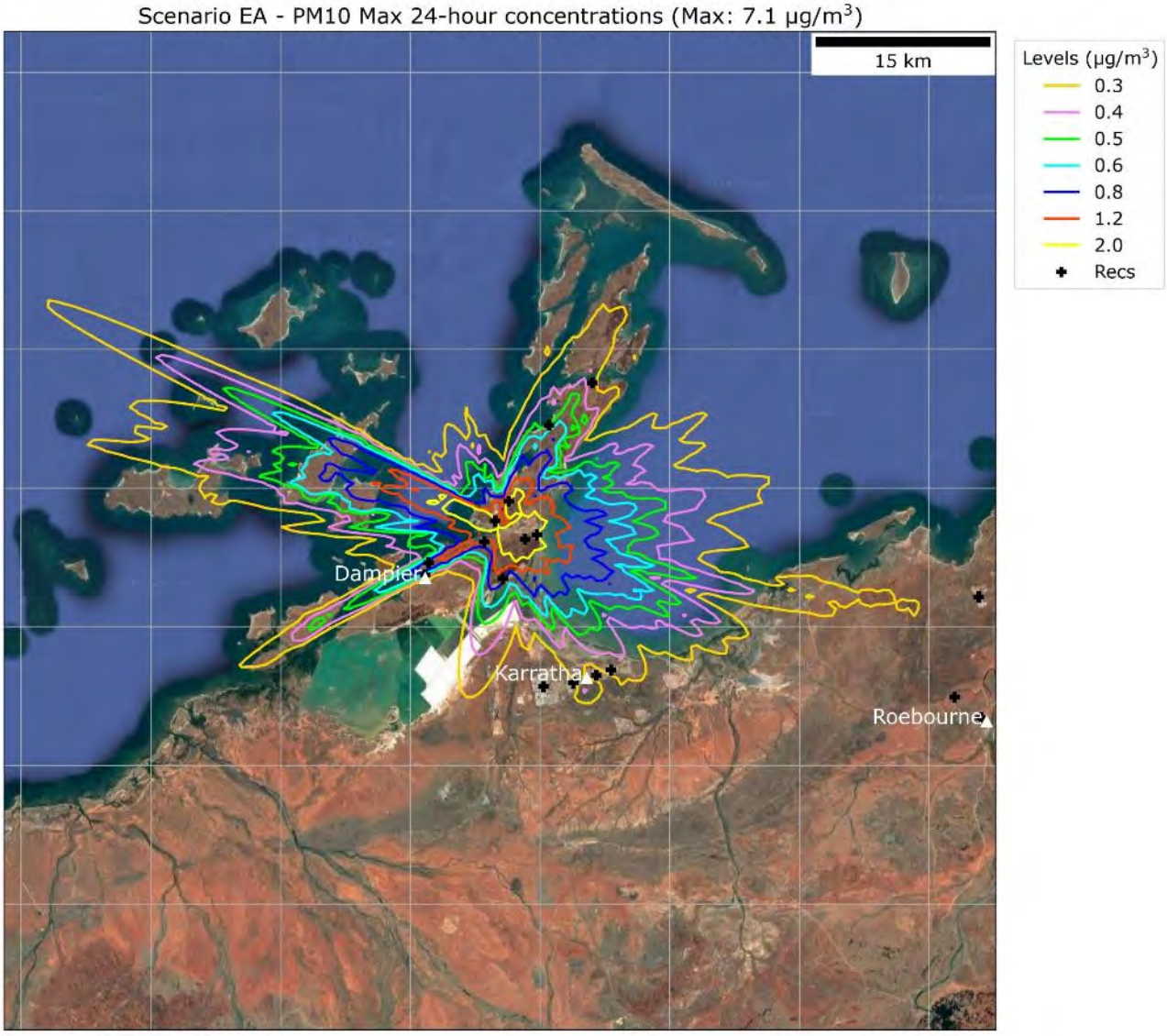

Figure 64. Contour levels of the maximum 24-hour concentrations of PM10. Scenario Ea.

Figure 65. Contour levels of the maximum 1-hour concentrations of SO_2. Scenario Ea.

10. CONCLUSION

The purpose of this study was to evaluate the effects of different flaring scenarios from Project Ceres. Among the possible flaring scenarios, a total of 12 has been selected: 7 single-flare scenarios and 5 simultaneous scenarios (i.e., with two flares active at the same time).

Calculations have been carried out determining the meteorological variables with 1-hour time resolution over an 80×80 km^2 domain (500 m grid resolution) for year 2014. This task was accomplished by using the WRF meteorological model with three nested domains, the inner one with a resolution of 3 km, and then with the CALMET diagnostic meteorological model.

The flare parameters have been calculated starting from the total heat released (equivalent height and diameter) and from the stream composition (emission rates of the pollutants). All the releases are characterised by very short durations: the longest one is less than one day, while the shortest one is less than one minute. However, in order to simulate the release even in the worst atmospheric conditions, the emissions have been considered active for the whole simulation year.

The atmospheric dispersion simulations have been undertaken by use of CALPUFF, which is a suitable atmospheric dispersion model widely used in the whole world. Ground Level Concentrations (GLCs) of nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and particulate matter (PM10) have been determined over the whole meteorological domain. The GLCs of the three gaseous pollutants have been compared against their ERPG-2 levels, while the GLCs of PM10 have been compared against the AQS.

The analysis shows that all flaring scenarios analysed comply with ERPG-2 levels set for nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and with the AQS level (24h average) for PM10.

ATTACHMENT 1 – IDENTIFIED POSSIBLE FLARING CASES

No.	Unit	Item Description	Fluid Description	Fluid Type (Liquid / Gas / Solid)	Destination	Continuous Normal (m^3/hr)	Continuous Max (m^3/hr)	Intermittent Max (kg/hr)	Intermittent Frequency (times/day)	Intermittent Duration (min)	Stream Composition	Note
FLARE LOAD OF AMMONIA PLANT												
A1	**1300**	**FE Start Up (Vent d/s V-311)**	**Hydrogen**	**Gas**	**Syngas Flare**	-	-	**65928**	**0 - 5 times per year**	**< 1 day**	**Ar= 0,09% mol CH4=1,47% mol CO=3,71% mol H2=92,69% mol N2=2% mol H2O=0,03% mol CO2=20ppm**	**Calculated Pollutant Emission rate: NOx: 35.28 g/s CO: 160.81 g/s PM: 40.11 g/s SOx: 0 g/s**
A2	1100 1200	Trip of ATR section	Process Gas	Gas	Syngas Flare	-	-	44024	0 - 5 times per year	<15 min	Ar=0,08% mol CH4= 6,80% mol CO= 8,75% mol CO2= 11,03% mol H2=45,83% mol N2=1,47% mol H20=26.05% mol	Calculated Pollutant Emission rate: NOx: 4.71 g/s CO: 21.45 g/s PM: 26.79 g/s SOx: 0 g/s
A3	1100	Trip & Depressurization of HDS section	Process Gas	Gas	Syngas Flare	-	-	64004	0 - 5 times per year	<15 min	Ar=0,06% mol CH4= 28,34 % mol CO= 6,50 % mol CO2= 8,59 % mol H2=34,18 % mol N2=2,5 % mol H20=19,03 % mol C2=0,72% mol C3=0,08% mol	Calculated Pollutant Emission rate: NOx: 11.62 g/s CO: 52.96 g/s PM: 38.94 g/s SOx: 0 g/s
A4	**1300**	**Trip of N2 wash unit**	**Process Gas**	**Gas**	**Syngas Flare**	-	-	**324720**	**0 - 5 times per year**	**< 1 day**	**Ar=0,06% mol CH4= 0,92% mol CO= 2,32% mol CO2= 19,41% mol H2=58% mol N2=1.25% mol H20=17,94% mol**	**Calculated Pollutant Emission rate: NOx: 28.82 g/s CO: 131.37 g/s PM: 197.54 g/s SOx: 0 g/s**
A5	1200 1300	Depressurization of NWU	Process Gas	Gas	Syngas Flare	-	-	393556	0 - 5 times per year	< 15 min	Ar=0,07% mol CH4= 1,16% mol CO= 2,93% mol CO2= 10,79% mol H2=73,39% mol N2=1,61% mol H20=9,99% mol	Calculated Pollutant Emission rate: NOx: 65.55 g/s CO: 298.82 g/s PM: 239.42 g/s SOx: 0 g/s

No.	Unit	Item Description	Fluid Description	Fluid Type (Liquid / Gas / Solid)	Destination	Continuous Normal (m^3/hr)	Continuous Max (m^3/hr)	Intermittent Max (kg/hr)	Intermittent Frequency (times/day)	Intermittent Duration (min)	Stream Composition	Note
FLARE LOAD OF AMMONIA PLANT												
A6	1100	Natural gas feed line 1100-E-224	Natural Gas	Gas	Syngas Flare	-	-	102471	1 time per 10years	< 1 hour	CH4= 89,99% mol CO2= 3% mol N2=4% mol H20=56 ppm Ethane=2,7% mol Isobutane=0,03% mol Propane=0,27% mol	Calculated Pollutant Emission rate: NOx: 35.8 g/s CO: 163.18 g/s PM: 62.34 g/s SOx: 0 g/s
A7	1100	1100-E-208 Waste heat boiler No.1	Process Gas	Gas	Syngas Flare	-	-	357192	1 time per 10years	< 1 hour	Ar=0,06% mol CH4= 0,92% mol CO= 18,08% mol CO2= 3,66% mol H2=42,26% mol N2=1,25% mol H20=33,69% mol	Calculated Pollutant Emission rate: NOx: 33.04 g/s CO: 150.6 g/s PM: 217.3 g/s SOx: 0 g/s
A8	**2500**	**2500-K-441 Discharge**	**Ammonia**	**Gas**	**Ammonia Flare**	-	-	**123416**	**1 time per 10years**	**< 1 hour**	**NH3= 100% mol**	**Support gas: 4700 kg/h** **Calculated Pollutant Emission rate:** **NOx: 4650.47 g/s** **CO: 92.55 g/s** **PM: 77.94 g/s** **SOx: 0.05 g/s**
A9	2500	2500-E-506 1st Ammonia chiller	Synthesis gas + Ammonia	Mixed	Ammonia Flare	-	-	17242	1 time per 10years	< 1 hour	Ar=0,32% mol H2=57,88% mol N2=19,29% mol NH3=22,5% mol	Calculated Pollutant Emission rate: NOx: 238.19 g/s CO: 12.82 g/s PM: 10.49 g/s SOx: 0 g/s
A10	**2500**	**2500-K-431 Syngas compressor**	**Syngas**	**Gas**	**Ammonia Flare**	-	-	**220000**	**0 - 5 times per year**	**< 1 min**	**N2=74,99% mol H2=25,01% mol Ar=17 ppm**	**Calculated Pollutant Emission rate: NOx: 5.03 g/s CO: 22.91 g/s PM: 133.84 g/s SOx: 0 g/s**

No.	Unit	Item Description	Fluid Description	Fluid Type (Liquid / Gas / Solid)	Destination	Continuous Normal (m^3/hr)	Continuous Max (m^3/hr)	Intermittent Max (kg/hr)	Intermittent Frequency (times/day)	Intermittent Duration (min)	Stream Composition	Note
FLARE LOAD OF AMMONIA PLANT												
A11	1100	Trip of ATR section + Natural gas feed line 1100-E-224	Process Gas	Gas	Syngas Flare	-	-	146495	0 - 5 times per year	< 15 min	Ar=0,03% mol CH4= 61,27%mol CO= 3,41 % mol CO2= 5,85 % mol H2=16,75 % mol N2=3,15% mol H20=7,57% mol C2=1,77% mol C3=0,02% mol C4=0,18% mol	Calculated Pollutant Emission rate: NOx: 41.03 g/s CO: 187.01 g/s PM: 89.12 g/s SOx: 0 g/s
A12	2500	2500-E-506 1st Ammonia chiller + 2500-K-431 Syngas compressor	Syngas * Ammonia	Mixed	Ammonia Flare	-	-	237242	1 time per 10years	< 1 min	Ar=0,03% mol H2=73,45% mol N2=24,5% mol NH3=2,02% mol	Calculated Pollutant Emission rate: NOx: 392.69 g/s CO: 185.82 g/s PM: 144.33 g/s SOx: 0 g/s

NOTE REGARDING POLLUTANTS EMISSION RATES CALCULATION FROM FLARING:
Flare combustion process is highly variable since primarily dependent on the flame stability.
Since combustion conditions depends on gas exit velocity, burner tube diameter (tip size), heat content, and wind conditions, international standards propose to estimate emissions from this equipment using factors.
The emission estimation perfomed considers:
- emission factor for NOx equal to 0.068 lb/106 Btu (Ref. AP-42, CH 13.5)
- emission factor for CO equal to 0.37 lb/106 Btu (Ref. AP-42, CH 13.5)
- stoichiometric conversion of Sulphur into SOx emissions
- efficiency reduction of NH3 to N2 equal to 95%. The remaining 5% is considered converted to NOx emissions
- emission factor for Soot equal to 0.00219 kg-PM/kg flare gas (ref. AP-42, Vol.1)

No.	Unit	Item Description	Fluid Description	Fluid Type (Liquid / Gas / Solid)	Destination	Continuous		Intermittent			Stream Composition	Note
						Normal	Max	Max	Frequency	Duration		
						Nm^3/hr	Nm^3/hr	Nm^3/hr	times/day	min		
FLARE LOAD OF UREA MELT TRAIN 1 (equivalent to TRAIN 2)												
U1	2610	M.P. section vent from C-103 through PV-1026B fully open H.P. synthesis loop instability during start-up	MP vent	Gas	2610-PK-112	-	-	9686	Two times during the first year of operation, than very remote	45 min	NH3 87.94% H2 0.81% N2 9.62% O2 1.41% Ar 0.15% CH4 0.02% CO 0.05% water sat.	Support gas: 395 kg/h Calculated Pollutant Emission rate: NOx: 243.75 g/s CO: 5.13 g/s PM: 5.03 g/s SOx: 0.01 g/s
U2	2610	M.P. section vent through PV-1026B partially open M.P. section instability	MP vent	Gas	2610-PK-112	-	-	2064	Event with very low frequency	1 hour	NH3 43.38% H2 3.79% N2 45.16% O2 6.63% Ar 0.70% CH4 0.09% CO 0.25% water sat.	Support gas: 320 kg/h Calculated Pollutant Emission rate: NOx: 25.75 g/s CO: 1.02 g/s PM: 1.47 g/s SOx: 0.01 g/s
U3	2610	Gas blow through 2610-LV-1022 2610-L-103 to 2610-C-135 Granulation unit in shut down	Vacuum vent	Gas	2610-PK-112	-	-	5738	Very remote event	10 min	NH3 64.7% CO2 0.9% H2O 34.4%	Support gas: 250 kg/h Calculated Pollutant Emission rate: NOx: 106.3 g/s CO: 2.35 g/s PM: 2.9 g/s SOx: 0.01 g/s
U4	**2610**	**Granulation unit in shut-down**	**MP + vacuum vent**	**Gas**	**2610-PK-112**	-	-	**1938**	**Once every 30 days**	**8 hours**	**NH3 – 0.56% H2 – 4.08% N2 – 49.71% O2 – 7.31% Ar – 0.71% CH4 – 0.1% CO – 0.28% H2O – 37.25%**	**Support gas: 395 kg/h Calculated Pollutant Emission rate: NOx: 0.46 g/s CO: 0.68 g/s PM: 1.48 g/s SOx: 0.01 g/s**
U5	2610	Tank in overpressure (2610-T-102) Gas blow through 2610-LV-1022 2610-L-103 to 2610-T-102	Tank vent	Gas	2610-PK-113	-	-	5738	Very remote event	10 min	NH3 64.7% CO2 0.9% H2O 34.4%	Support gas: 250 kg/h Calculated Pollutant Emission rate: NOx: 106.3 g/s CO: 2.35 g/s PM: 2.9 g/s SOx: 0.01 g/s

No.	Unit	Item Description	Fluid Description	Fluid Type (Liquid / Gas / Solid)	Destination	Continuous		Intermittent			Stream Composition	Note
						Normal	Max	Max	Frequency	Duration		
						Nm³/hr	Nm³/hr	Nm³/hr	times/day	min		
FLARE LOAD OF UREA MELT TRAIN 1 (equivalent to TRAIN 2)												
U6	**2610**	**H.P. section vent from 2610-V-101 through 2610-PV-1021B fully open) H.P. synthesis loop instability during start-up**	**HP vent**		**2610-PK-113**	-	-	**36300**	**Remote**	**10 min**	**NH3 93.38% H2 nill. N2 2.30% O2 0.35% CO2 1.14% Ar 0.03% CH4 0.005% CO 0.014% H2O 2.78%**	**Support gas: 1430 kg/h Calculated Pollutant Emission rate: NOx: 969.79 g/s CO: 20.02 g/s PM: 18.28 g/s SOx: 0.02 g/s**
U7	2610	H.P. section vent from 2610-V-101 through 2610-PV-1021B partially open H.P. synthesis loop instability	HP vent		2610-PK-113	-	-	11036	Remote	10 min	NH3 87.45% H2 nill. N2 7.58% O2 1.14% CO2 1.06% Ar 0.094% CH4 0.018% CO 0.047% H2O 2.60%	Support gas: 560 kg/h Calculated Pollutant Emission rate: NOx: 276.22 g/s CO: 5.95 g/s PM: 5.84 g/s SOx: 0.01 g/s
U8	**2610**	**M.P. sect. instability during start-up (2610-C-101 draining to 2610-V-106) PCT/2610-C-102 top diverted to flare During start-up / long shut-down**	**LP + PCT vent**		**2610-PK-113**	-	-	**12100**	**Event with very low frequency**	**30 min**	**NH3 63% CO2 1 % H2O 36%**	**Support gas: 600 kg/h Calculated Pollutant Emission rate: NOx: 218.31 g/s CO: 4.95 g/s PM: 6.17 g/s SOx: 0.01 g/s**
U9	**2610**	**LP section vent from 2610-C-104 through 2610-PV-1033 partially open PCT during process upset (2610-C-102 top diverted to flare)**	**LP + PCT vent**		**2610-PK-113**	-	-	**14800**	**Event with very low frequency**	**1 hour**	**NH3 54,1% CO2 5,4 % H2O 40,5%**	**Support gas: 650 kg/h Calculated Pollutant Emission rate: NOx: 229.35 g/s CO: 5.23 g/s PM: 7.99 g/s SOx: 0.01 g/s**
U10	2610	NH3 From 2610-V-105	Emergency process relief		2610-PK-113	-	-	18800	1 time per 10years	2 min	NH3 100 % vol	Support gas: 720 kg/h Calculated Pollutant Emission rate: NOx: 537.75 g/s CO: 10.99 g/s PM: 9.12 g/s SOx: 0.01 g/s

No.	Unit	Item Description	Fluid Description	Fluid Type (Liquid / Gas / Solid)	Destination	Continuous		Intermittent			Stream Composition	Note
						Normal	Max	Max	Frequency	Duration		
						Nm^3/hr	Nm^3/hr	Nm^3/hr	times/day	min		
FLARE LOAD OF UREA MELT TRAIN 1 (equivalent to TRAIN 2)												
U11	2610	NH3 From 2610-V-105	Emergency process relief		2610-PK-113	-	-	5800	1 time per 10years	2min	NH3 100 % vol	Support gas: 220 kg/h Calculated Pollutant Emission rate: NOx: 165.9 g/s CO: 3.39 g/s PM: 2.82 g/s SOx: 0.01 g/s

NOTE REGARDING POLLUTANTS EMISSION RATES CALCULATION FROM FLARING:

Flare combustion process is highly variable since primarily dependent on the flame stability.

Since combustion conditions depends on gas exit velocity, burner tube diameter (tip size), heat content, and wind conditions, international standards propose to estimate emissions from this equipment using factors.

The emission estimation perfomed considers:

- emission factor for NOx equal to 0.068 lb/106 Btu (Ref. AP-42, CH 13.5)
- emission factor for CO equal to 0.37 lb/106 Btu (Ref. AP-42, CH 13.5)
- stoichiometric conversion of Sulphur into SOx emissions
- efficiency reduction of NH3 to N2 equal to 95%. The remaining 5% is considered converted to NOx emissions
- emission factor for Soot equal to 0.00219 kg-PM/kg flare gas (ref. AP-42, Vol.1)

No.	Unit	Item Description	Fluid Description	Fluid Type (Liquid / Gas / Solid)	Destination	Continuous		Intermittent			Stream Composition	Note
						Normal (m^3/hr)	Max (m^3/hr)	Max (kg/hr)	Frequency (times/day)	Duration (min)		
FLARE LOAD OF AMMONIA STORAGE FLARE												
S1	4210	BOG from Refrigerated Ammonia Storage Tank due to Ammonia BOG Refrigeration Package unavailability	Ammonia	Gas	3430-PK-103	-	-	1570	1 time per 10years	8 hours	100% NH3	Support gas: 90 kg/h Calculated Pollutant Emission rate: NOx: 59.17 g/s CO: 1.23 g/s PM: 1.01 g/s SOx: 0.01 g/s
S2	4210	Ammonia BOG compressor blocked outlet	Ammonia	Gas	3430-PK-103	-	-	2620	1 time per 10years	< 1 hour	100% NH3	Support gas: 130 kg/h Calculated Pollutant Emission rate: NOx: 98.74 g/s CO: 2.02 g/s PM: 1.68 g/s SOx: 0.01 g/s

NOTE REGARDING POLLUTANTS EMISSION RATES CALCULATION FROM FLARING:
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Since combustion conditions depends on gas exit velocity, burner tube diameter (tip size), heat content, and wind conditions, international standards propose to estimate emissions from this equipment using factors.
The emission estimation perfomed considers:
- emission factor for NOx equal to 0.068 lb/106 Btu (Ref. AP-42, CH 13.5)
- emission factor for CO equal to 0.37 lb/106 Btu (Ref. AP-42, CH 13.5)
- stoichiometric conversion of Sulphur into SOx emissions
- efficiency reduction of NH3 to N2 equal to 95%. The remaining 5% is considered converted to NOx emissions
- emission factor for Soot equal to 0.00219 kg-PM/kg flare gas (ref. AP-42, Vol.1)