Annex 5A

Key Input Data for the QRA Study

5A KEY INPUT DATA FOR THE QRA STUDY

This *Annex* summarises the key input data for the QRA Study as follows:

- ***Section 5A.1*** – Surrounding Population;
- ***Section 5A.2*** – Meteorological Data;
- ***Section 5A.3*** – Failure Frequency;
- ***Section 5A.4*** – Ignition Probability;
- ***Section 5A.5*** – Explosion Probability; and
- ***Section 5A.6*** – Consequence End-Point Criteria.

5A.1 SURROUNDING POPULATION

5A.1.1 QRA Study for Marine Transit of the LNGC and FSRU Vessel to the LNG Terminal

Surrounding Marine Vessel Population

Population in Marine Vessels

The marine traffic in the vicinity of the transit route of LNGC and FSRU Vessel includes fishing vessels, rivertrade coastal vessels, ocean-going vessels, fast launches, fast ferries, and other types of smaller vessels.

The marine vessel population used in the QRA Study are given in ***Table 5A.1***. The figures are based on Marine Traffic Impact Assessment (MTIA) Report (1) except for fast ferries. The maximum population of fast ferries is assumed to be 450, based on the maximum capacity of the largest ferry operating in the area. However, the average load factors for fast ferries to Macau and Pearl Rivers ports are 62% and 47% respectively (2). Hence, a distribution in ferry population was assumed as indicated in ***Table 5A.1***. This distribution gives an overall load factor of about 58% which is conservative and covers any future increase in marine vessel population. There is an additional category in the traffic volume data called "Others". These are assumed to be small marine vessels with a population of 5.

(1) BMT Asia Pacific Ltd., Marine Impact Assessment for Black Point & Soko islands LNG Receiving Terminal & Associated Facilities, Pipeline Issues, Working Paper #3, Issue 6, May 2006.

(2) *Passenger Arrivals/Departures and Passenger Load Factors at Cross-Boundary Ferry Terminals*, January to December 2014, Marine Department, Hong Kong SAR.

Table 5A.1 Marine Vessel Population

Type of Marine Vessel	Average Population per Vessel	
Ocean-Going Vessel	21	
Rivertrade Coastal Vessel	5	
Fast Ferries	450	(largest ferries with max population)
	350	(typical ferry with max population)
	280	(typical ferry at 80% capacity)
	175	(typical ferry at 50% capacity)
	105	(typical ferry at 30% capacity)
	35	(typical ferry at 10% capacity)
Tug and Tow	5	
Others	5	

Protection Factors for Marine Vessel

Population on marine vessels is considered to be provided with some protection from the vessel structure. The degree of protection offered depends on factors such as:

- Size of vessel;
- Construction material and likelihood of secondary fires;
- Speed of vessel and hence its exposure time to the flammable cloud;
- The proportion of passengers likely to be on deck or in the interior of the vessel; and
- The ability of gas to penetrate into the interior of the vessel and form a flammable mixture.

Small vessels such as fishing boats provide little protection while larger vessels such as ocean-going vessels provide greater protection. Fast ferries are air conditioned and have limited rate of air exchange with outside environment. Based on these considerations, the fatality probabilities and the population at risk adopted for each type of marine vessel are given in ***Table 5A.2***, in line with the previous studies that have been approved by EPD and other relevant authorities (1) (2).

(1) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

(2) ERM, EIA for *Black Point Gas Supply Project* (Register No.: AEIAR-150/2010), February 2010.

Table 5A.2 Population at Risk

Marine Vessel Type	Population	Fatality Probability (1)(2)	Population at Risk (1)(2)
Ocean-Going Vessel	21	0.1	2
Rivertrade Coastal Vessel	5	0.3	2
Fast Ferries			
(largest ferries with max population)	450	0.3	135
(typical ferry with max population)	350	0.3	105
(typical ferry at 80% capacity)	280	0.3	84
(typical ferry at 50% capacity)	175	0.3	53
(typical ferry at 30% capacity)	105	0.3	32
(typical ferry at 10% capacity)	35	0.3	11
Tug and Tow	5	0.9	5
Others	5	0.9	5

Estimation of Number of Marine Vessels per Day

In the QRA Study, the marine traffic population in the vicinity of the Project components has been considered as both point receptors and average density values. The population of all marine vessels was treated as an area average density except for fast ferries which are treated as point receptors.

As shown in ***Figure 5A.1***, the marine area in the vicinity of the Project components has been divided into 12.67 km^2 grid cells, each grid being approximately 3.6 km × 3.6 km. The time for a marine vessel to traverse a grid was calculated based on the travel distance divided by the marine vessel's average speed. The average speed and transit time for different vessel types are presented in ***Table 5A.3***, in line with the previous EIA Reports that were approved by the EPD and other relevant authorities [1] [2].

Table 5A.3 Average Speed and Transit Time of Different Marine Vessel Type

Marine Vessel Type	Typical Speed ($m\ s^{-1}$) (1)(2)	Transit Time (min) (1)(2)
Ocean-Going Vessel	6.0	9.9
Rivertrade Coastal Vessel	6.0	9.9
Fast Ferries	15.0	4.0
Tug and Tow	2.5	23.7
Others	6.0	9.9

The number of marine vessels traversing each grid daily [3] are given in ***Table 5A.4***, where the grid cell reference numbers are defined according to ***Figure 5A.1***.

(1) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

(2) ERM, EIA for *Black Point Gas Supply Project* (Register No.: AEIAR-150/2010), February 2010.

(3) BMT Asia Pacific Limited, Hong Kong Offshore LNG Terminal FSRU Terminal MTIA Report, R9331.05

The number of marine vessels present within each grid cell at any instant in time was then calculated from:

Number of vessels = No. of vessels per day × Grid length / 86,400 / Speed
(Equation 1)

The values obtained represent the number of marine vessels present within a grid cell at any instant in time. Values of less than one are interpreted as the probability of a vessel being present. The number of marine vessels per day is summarised in ***Table 5A.4***.

Table 5A.4 Number of Marine Vessels per Day

Grid No.	Average Number of Marine Vessel per Day									
	2020					2030				
	OG	RT	TT	FF(*)	OTH	OG	RT	TT	FF(*)	OTH
1	1	6	6	0	87	1	7	7	0	104
2	1	8	9	0	135	1	8	9	0	163
3	1	14	10	0	184	1	14	10	0	221
4	1	20	9	0	151	1	20	9	0	182
5	3	26	14	0	103	3	26	14	0	124
6	18	45	21	0	205	19	46	21	0	247
7	23	31	10	0	211	25	32	10	0	254
8	167	27	8	0	114	178	27	8	0	137
9	116	24	11	0	130	124	25	11	0	156
10	3	6	4	0	87	3	7	4	0	104

OG: Ocean-Going Vessel
RT: Rivertrade Costal Vessel
TT: Tug & Tow Vessels
FF: Fast Ferries
OTH: Others
(*): Fast ferries are treated separately

Estimation of Marine Populations (Average Density Approach)

The average marine population for each grid was calculated by combining the number of marine vessels in each grid as per *Equation 1* with the population at risk for each marine vessel shown in ***Table 5A.2***. The estimated marine populations for the assessment years is summarised in ***Table 5A.5***. This grid population is assumed to apply to all time periods.

Table 5A.5 Estimated Marine Populations for the Assessment Years

Marine Grid No.	2020	2030
Grid No. 1	4.31	5.09
Grid No. 2	6.51	7.59
Grid No. 3	8.73	10.15
Grid No. 4	7.59	8.79
Grid No. 5	6.76	7.57
Grid No. 6	14.51	16.33
Grid No. 7	13.99	16.01
Grid No. 8	33.24	35.91
Grid No. 9	25.76	28.09
Grid No. 10	6.51	7.59

It is noted however that fast ferries are excluded since they were treated separately in the analysis (see below).

When simulating a possible release scenario, the impact area was calculated from dispersion modelling. In general, only a fraction of the grid area was affected and hence the number of fatalities within a grid was calculated using the following equation, in line with the previous studies that have been approved by the EPD and other relevant authorities (1) (2):

Number of Fatality = Grid Population × Impact Area / Grid Area

(Equation 2)

Estimation of Fast Ferry Population (Point Receptor Approach)

The average density approach, described above, effectively dilutes the population over the area of the grid. Given that fast ferries have a much higher population than other classes of vessel, combined with a relatively low presence factor due to their higher speed, the average density approach would not adequately address the impact of fast ferries on the F-N curves. Fast ferries were therefore treated differently in the QRA Study.

In reality, if a fast ferry is affected by an accident scenario, the whole ferry will likely be affected. The likelihood that the ferry is affected, however, depends on the size of the hazard area and the density of ferry vessels. To model this, the population is treated as a concentrated point receptor, i.e. the entire population of the ferry is assumed to remain focused at the ferry location. The ferry density is calculated the same way as described above (*Equation 1*), giving the number of ferries per grid at any instant in time, or equivalent a "presence factor". A hazard scenario, however, will not affect a whole grid, but some fraction determined by the area ratio of the hazard footprint area and the grid area.

In line with the previous studies that have been approved by the EPD and other relevant authorities (1) (2), the presence factor corrected by this area ratio was then used to modify the frequency of the hazard scenario using the following equation:

Probability that ferry is affected = Presence Factor × Impact Area / Grid Area

(Equation 3)

The fast ferry population distribution adopted is described in ***Table 5A.6***. Information from the main ferry operators suggested that 25% of ferry trips take place at night time (between 7 pm and 7 am), while 75% occur during daytime. Day and night ferries are therefore assessed separately in the QRA Study. This

(1) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

(2) ERM, EIA for *Black Point Gas Supply Project* (Register No.: AEIAR-150/2010), February 2010.

approach is consistent with the previous EIA studies that were approved by the EPD and other relevant authorities [(1)] [(2)].

Table 5A.6 Fast Ferry Population Distribution for Day and Night Time Periods

Population	Population at Risk	% of Day Trips	% of Night Trips	% of All Trips (= 0.75 × day + 0.25 × night)
450[a]	135	5	-	3.75
350[b]	105	5	-	3.75
280[c]	84	30	-	22.50
175[d]	53	60	30	52.50
105[e]	32	-	50	12.50
35[f]	11	-	20	5.00

Note:
a: largest ferries with max population
b: typical ferry with max population
c: typical ferry at 80% capacity
d: typical ferry at 50% capacity
e: typical ferry at 30% capacity
f: typical ferry at 10% capacity

The ferry presence factor (*Equation 1*) and probability that a ferry is affected by a release scenario (*Equation 2*) were calculated for each ferry occupancy category and each time period.

Surrounding Land and Road Traffic Population

Based on the detailed consequence analysis for marine transit of LNGC and FSRU Vessel to the LNG Terminal, all potential hazardous consequence for the marine transit of LNGC and FSRU Vessel could not reach any land based population (building development) and road traffic population. Therefore, land based population (building development) and road traffic population do not affect the societal risk levels and therefore are not considered in the QRA Study.

5A.1.2 QRA Study for the LNG Terminal

Surrounding Marine Vessel Population

The marine traffic population in the vicinity of the LNG Terminal was estimated using the same approach as described in ***Section 5A.1.1***. The number of marine vessels per day and the estimated marine population in the vicinity of the LNG Terminal are referred to Grid No. 1, 2 and 3, as summarised in ***Table 5A.4*** and ***Table 5A.5***.

(1) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

(2) ERM, EIA for *Black Point Gas Supply Project* (Register No.: AEIAR-150/2010), February 2010.

Surrounding Land and Road Traffic Population

Based on the detailed consequence analysis, all potential hazardous consequence does not reach any land based population (building development) and road traffic population. Therefore, land based population (building development) and road traffic population do not affect the societal risk levels and therefore are not considered in the QRA Study.

5A.1.3 QRA Study for the Subsea Pipelines

Surrounding Marine Vessel Population

The marine traffic population in the vicinity of the BPPS and LPS Pipelines was estimated using the same approach as described in ***Section 5A.1.1***. The marine traffic data [1] [2] for the BPPS and LPS Pipelines are summarised in ***Table 5A.7*** to ***Table 5A.10*** for each assessment year.

Table 5A.7 Traffic Volume for BPPS Pipeline in 2020 – Operational Year

Segment		Fishing	Traffic Volume (Ships/day) River-trade	Ocean-going	Fast Ferry	Others	Total
X	Jetty Approach to South of Soko Islands	2	34	5	5	68	114
A	Southwest of Soko Islands	2	9	2	5	20	38
B	Southwest of Fan Lau	2	15	0	179	68	264
C	Southwest Lantau	2	27	3	2	18	52
D	West of Tai O	3	9	0	0	9	21
E	West of HKIA	15	51	0	47	74	187
F	West of Sha Chau	2	2	0	0	20	24
G	West of Lung Kwu Chau	10	16	0	0	17	43
H	Lung Kwu Chau to Urmston Anchorage	8	12	0	81	24	125
I	Urmston Road	15	206	61	70	154	506
J	West of BPPS	20	26	0	39	42	127

Table 5A.8 Traffic Volume for BPPS Pipeline in 2030 – Future Scenario Year

Segment		Fishing	Traffic Volume (Ships/day) River-trade	Ocean-going	Fast Ferry	Others	Total
X	Jetty Approach to South of Soko Islands	4	35	5	5	82	131
A	Southwest of Soko Islands	4	9	2	5	24	44
B	Southwest of Fan Lau	4	15	0	198	82	299
C	Southwest Lantau	4	28	3	2	22	59
D	West of Tai O	5	9	0	0	11	25
E	West of HKIA	17	53	0	52	90	212
F	West of Sha Chau	4	2	0	0	24	30
G	West of Lung Kwu Chau	12	17	0	0	20	49

(1) BMT Asia Pacific Limited, Black Point Pipeline MTIA Report, R.9331.03

(2) BMT Asia Pacific Limited, Lamma Pipeline MTIA Report, R.9331.02

Segment		Fishing	Traffic Volume (Ships/day) River-trade	Ocean-going	Fast Ferry	Others	Total
H	Lung Kwu Chau to Urmston Anchorage	10	13	0	88	30	141
I	Urmston Road	17	214	65	76	188	560
J	West of BPPS	22	27	0	43	51	143

Table 5A.9 Traffic Volume for LPS Pipeline in 2020 – Operational Year

Segment		Fishing	Traffic Volume (Ships/day) River-trade	Ocean-going	Fast Ferry	Others	Total
A	Jetty Approach to South of Shek Kwu Chau	5	2	0	0	67	74
B	South of Cheung Chau	6	10	3	0	188	207
C	West Lamma Channel	3	6	3	0	29	41
D	Alternative Shore Approach	6	16	2	0	45	69

Table 5A.10 Traffic Volume for LPS Pipeline in 2030 – Future Scenario Year

Segment		Fishing	Traffic Volume (Ships/day) River-trade	Ocean-going	Fast Ferry	Others	Total
A	Jetty Approach to South of Shek Kwu Chau	7	4	0	0	81	92
B	South of Cheung Chau	9	12	3	0	229	253
C	West Lamma Channel	5	9	3	0	35	52
D	Alternative Shore Approach	9	19	2	0	55	85

Surrounding Land and Road Traffic Population

Based on the detailed consequence analysis, all potential hazardous consequence could not reach any land based population (building development) and road traffic population. Therefore, land based population (building development) and road traffic population do not affect the societal risk levels and therefore are not considered in the QRA Study.

5A.1.4 *QRA Study for the GRSs at the BPPS and the LPS*

Surrounding Marine Vessel Population

The marine traffic population in the vicinity of the GRSs at the BPPS and LPS was estimated using the same approach as described in ***Section 5A.1.1***. The grid cell reference numbers are defined according to ***Figure 5A.2***.

The number of marine vessels per day (1) in the vicinity of the GRSs at the BPPS and LPS is summarised in ***Table 5A.11***. The estimated marine population at each marine grid for the assessment years are summarised in ***Table 5A.12***.

(1) BMT Asia Pacific Limited, HOLD

Table 5A.11 Number of Marine Vessels per Day

Grid No.	Average Number of Marine Vessel per Day									
	2020					2030				
	OG	RT	TT	FF(*)	OTH	OG	RT	TT	FF(*)	OTH
GRS at the BPPS										
11	74	209	9	134	275	79	214	9	142	332
12	79	167	8	163	211	85	171	8	173	254
13	0	24	4	70	27	0	25	4	74	33
14	14	96	5	73	130	15	98	5	78	156
GRS at the LPS										
15	3	61	9	177	232	3	63	9	196	280
16	1	18	5	0	238	1	19	5	0	286
17	160	29	15	0	318	171	30	15	0	384
18	1	10	3	0	119	1	10	3	0	143

OG: Ocean-Going Vessel
RT: Rivertrade Costal Vessel
TT: Tug & Tow Vessels
FF: Fast Ferries
OTH: Others
(*): Fast ferries are treated separately

Table 5A.12 Estimated Marine Populations for the Assessment Years

	Marine Grid No.	2020	2030
GRS at the BPPS			
	Grid No. 11	31.50	34.70
	Grid No. 12	28.13	30.91
	Grid No. 13	2.34	2.61
	Grid No. 14	11.45	12.69
GRS at the LPS			
	Grid No. 15	12.62	14.55
	Grid No. 16	10.50	12.39
	Grid No. 17	40.70	45.07
	Grid No. 18	5.42	6.34

Surrounding Land Population

Based on a review of the GeoInfo Map [1], there is no land based population (building development) in the vicinity of the BPPS and LPS. A site survey was also conducted to verify the desktop review findings.

The nearest industrial facilities in Lung Kwu Sheung Tan are about 1.5 km away from the GRS area of the BPPS, while the nearest residential area in Tai Wan Tsuen and the nearest public facilities at Hung Shing Ye Beach are about 1.6 km and 1.7 km, respectively away from the GRS area of the LPS.

Based on the detailed consequence analysis, all potential hazardous consequence could not reach any land based population (building development). Therefore, land based population (building development) do not affect the societal risk levels and therefore are not considered in the QRA Study.

(1) GeoInfo Map, http://www.map.gov.hk (assessed 7th August 2017)

Surrounding Road Traffic Population

Based on the detailed consequence analysis, the potential hazardous consequence can reach Yung Long Road, which is the only road accessing the BPPS.

In order to estimate the road traffic population for Yung Long Road, population estimation for the nearby Lung Kwu Tan Road was conducted. As per 2015 Annual Traffic Census (1), which is the latest available road traffic data, the Annual Average Daily Traffic (AADT) value is 4,980 vehicles per day for station number 5481 from Lung Fai Street to Tsang Kok. With an assumed average speed of 50 km hr^{-1} and an average of three (3) persons per vehicle, the number of persons on the road was estimated as:

No. of persons = (4,980 × Vehicle Occupancy / 24 / Vehicle Speed)
= 4,980 × 3 / 24 / 50
= 12.5 persons km^{-1}

The average annual traffic growth at Lung Kwu Tan Road from Year 2005 to Year 2015 (2) is 1.8%. As a conservative approach, 2% of annual traffic growth at Lung Kwu Tan Road was adopted in the QRA Study to forecast the road population for operational year in 2020 and future scenario year in 2030.

In order to estimate the road traffic population for Yung Long Road, the traffic flow of Yung Long Road was assumed as 10% of day-time traffic flow from Lung Kwu Tan Road, and 10% of day-time traffic flow was assumed during the night-time in the QRA Study(3).

No traffic road population was identified in the vicinity of the LPS.

5A.2 METEOROLOGICAL DATA

The latest available 5-year meteorological data on the local meteorological conditions such as wind speed, wind direction, atmospheric stability class, temperature, and relative humidity were obtained from the Hong Kong Observatory.

The annual average temperature and relative humidity have been taken as 23.3 °C and 78% respectively according to *1982 – 2010 Normals Hong Kong* (4).

Meteorological data from Cheung Chau, Sha Chau and Lamma Island Weather Stations were analysed and summarised at ***Table 5A.13***, ***Table 5A.14*** and ***Table 5A.15***.

The Pasquill-Gifford atmosphere stability classes range from A through F.

(1) Transport Department, The Annual Traffic Census 2015

(2) Transport Department, The Annual Traffic Census 2005-2015

(3) ERM, EIA for *Additional Gas-fired Generation Units Project* (Register No.: AEIAR-197/2016), June 2016.

(4) Hong Kong Observatory

A: Turbulent
B: Very unstable
C: Unstable
D: Neutral
E: Stable
F: Very stable

Wind speed and solar radiation interact to determine the level of atmospheric stability, which in turn suppresses or enhances the vertical element of turbulent motion. The latter is a function of the vertical temperature profile in the atmosphere; the greater the rate of decrease in temperature with height, the greater the level of turbulence.

Class A represents extremely unstable conditions, which typically occur under conditions of strong daytime insolation. Class D is neutral and neither enhances nor suppresses atmospheric turbulence. Class F on the other hand represents stable conditions, which typically arise on clear nights with little wind.

Table 5A.13 Data from Cheung Chau Weather Station (2012 - 2016)

	Day				**Night**			
Wind Speed (m s^{-1})	**2.5**	**3.0**	**7.0**	**2.0**	**2.5**	**3.0**	**7.0**	**2.0**
Atmospheric Stability	**B**	**D**	**D**	**F**	**B**	**D**	**D**	**F**
Wind Direction								
0°	4.14%	0.81%	7.77%	0.54%	0.00%	0.86%	12.73%	2.22%
30°	3.61%	1.04%	4.25%	0.66%	0.00%	1.16%	6.20%	2.38%
60°	2.68%	0.69%	2.48%	0.42%	0.00%	0.92%	5.03%	2.29%
90°	3.37%	0.62%	10.94%	0.33%	0.00%	1.11%	21.03%	2.47%
120°	10.73%	0.75%	9.91%	0.34%	0.00%	0.54%	11.19%	2.39%
150°	6.16%	0.55%	2.19%	0.28%	0.00%	0.22%	3.07%	1.44%
180°	3.67%	0.53%	1.59%	0.26%	0.00%	0.24%	3.74%	1.40%
210°	5.38%	0.51%	3.48%	0.15%	0.00%	0.28%	5.34%	1.30%
240°	2.42%	0.30%	0.87%	0.16%	0.00%	0.31%	2.25%	1.54%
270°	1.15%	0.29%	0.70%	0.20%	0.00%	0.21%	2.17%	1.25%
300°	0.60%	0.26%	0.29%	0.18%	0.00%	0.14%	0.40%	0.97%
330°	0.96%	0.16%	0.50%	0.14%	0.00%	0.09%	0.58%	0.56%

Table 5A.14 Data from Sha Chau Weather Station (2010 - 2014)

	Day				**Night**			
Wind Speed (m s^{-1})	**2.5**	**3.0**	**7.0**	**2.0**	**2.5**	**3.0**	**7.0**	**2.0**
Atmospheric Stability	**B**	**D**	**D**	**F**	**B**	**D**	**D**	**F**
Wind Direction								
0°	7.61%	0.57%	13.18%	0.26%	0.00%	0.56%	12.39%	0.85%
30°	1.04%	0.44%	4.86%	0.24%	0.00%	0.56%	9.07%	0.86%
60°	0.67%	0.39%	0.87%	0.22%	0.00%	0.67%	2.52%	1.07%
90°	4.36%	0.94%	5.52%	0.34%	0.00%	1.39%	11.75%	2.75%
120°	7.06%	0.75%	15.48%	0.42%	0.00%	0.92%	24.71%	2.33%

	Day				Night			
150°	1.37%	0.28%	2.30%	0.20%	0.00%	0.29%	4.03%	1.21%
180°	3.66%	0.38%	4.29%	0.21%	0.00%	0.25%	5.37%	1.10%
210°	7.77%	0.61%	7.11%	0.35%	0.00%	0.35%	9.91%	1.43%
240°	0.02%	0.01%	0.01%	0.02%	0.00%	0.00%	0.01%	0.10%
270°	0.02%	0.01%	0.00%	0.01%	0.00%	0.00%	0.00%	0.02%
300°	0.29%	0.05%	0.00%	0.03%	0.00%	0.02%	0.00%	0.09%
330°	3.00%	0.25%	2.37%	0.17%	0.00%	0.25%	2.60%	0.56%

Table 5A.15 Data from Lamma Island Weather Station (2012 - 2016)

	Day				Night			
Wind Speed (m s^{-1})	**2.5**	**3.0**	**7.0**	**2.0**	**2.5**	**3.0**	**7.0**	**2.0**
Atmospheric Stability	**B**	**D**	**D**	**F**	**B**	**D**	**D**	**F**
Wind Direction								
0°	1.68%	1.49%	0.71%	1.44%	0.00%	1.36%	2.06%	6.62%
30°	0.46%	0.35%	0.06%	0.50%	0.00%	0.33%	0.16%	2.74%
60°	2.33%	1.18%	0.76%	1.05%	0.00%	1.05%	0.91%	4.80%
90°	12.28%	2.47%	13.72%	1.83%	0.00%	3.72%	22.25%	17.81%
120°	9.93%	1.45%	2.43%	1.11%	0.00%	1.42%	2.93%	6.07%
150°	1.52%	0.38%	0.13%	0.18%	0.00%	0.20%	0.26%	1.02%
180°	0.71%	0.21%	0.03%	0.12%	0.00%	0.04%	0.02%	0.70%
210°	7.71%	0.83%	2.09%	0.38%	0.00%	0.55%	3.60%	3.16%
240°	5.50%	0.53%	0.51%	0.28%	0.00%	0.15%	0.59%	1.57%
270°	2.02%	0.28%	0.08%	0.12%	0.00%	0.05%	0.14%	0.83%
300°	3.49%	0.32%	1.09%	0.33%	0.00%	0.07%	0.70%	0.85%
330°	6.31%	1.53%	5.43%	0.71%	0.00%	0.98%	8.04%	2.26%

5A.3 FAILURE FREQUENCY

5A.3.1 QRA Study for Marine Transit of the LNGC and FSRU Vessel to the LNG Terminal

Collision Frequency

The total collision frequencies leading to breach of LNG are [1] summarised in the following tables:

Table 5A.16 Total Collision Frequency Leading to Breach of LNG (Year 2020)

Type of LNGC	Release Frequency in Sub-Segment "a" (/m/year)	Release Frequency in Sub-Segment "b" (/m/year)
Small LNGC	1.6×10^{-8}	1.5×10^{-9}
Large LNGC	1.6×10^{-8}	1.5×10^{-9}

(1) BMT Asia Pacific Limited, Hong Kong Offshore LNG Terminal FSRU Terminal MTIA Report, R9331.05

Table 5A.17 Total Collision Frequency Leading to Breach of LNG (Year 2030)

Type of LNGC	Release Frequency in Sub-Segment "a" (/m/year)	Release Frequency in Sub-Segment "b" (/m/year)
Small LNGC	1.7×10^{-8}	4.9×10^{-10}
Large LNGC	1.8×10^{-8}	5.2×10^{-10}

Grounding Frequency

Considering the number of marine transits per year and the probability of LNG breach upon grounding events, the grounding release frequency adopted in the QRA Study was 1.2×10^{-6} per km per year. The derivation of this grounding frequency is provided in ***Annex 5F***.

Release Hole Sizes

The selected release hole sizes and associated penetration energy are presented in the following table, which is in line with the previous EIA Report that has been approved by the EPD [1].

Table 5A.18 Release Hole Sizes and Penetration Energy

Release Hole Size	Penetration Energy (MJ)
250 mm	100 to 110 MJ
750 mm	111 to 150 MJ
1500 mm	>150 MJ

5A.3.2 QRA Study for LNG Terminal

The release event frequencies are referred from OGP [2] and summarised in ***Table 5A.19***.

Table 5A.19 Release Event Frequencies

Equipment	Release Scenario	Release Phase	Release Frequency	Unit	Reference
Piping 2" to 6"	10 mm hole	Liquid/ Gas	3.45E-05	per metre per year	OGP
	25 mm hole	Liquid/ Gas	2.70E-06	per metre per year	OGP
	50 mm hole	Liquid/ Gas	6.00E-07	per metre per year	OGP
Piping 8" to 12"	10 mm hole	Liquid/ Gas	3.06E-05	per metre per year	OGP
	25 mm hole	Liquid/ Gas	2.40E-06	per metre per year	OGP
	50 mm hole	Liquid/ Gas	3.70E-07	per metre per year	OGP

(1) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

(2) OGP, *Risk Assessment Data Directly, Report No. 434-.1*, March 2010.

Equipment	Release Scenario	Release Phase	Release Frequency	Unit	Reference
	>150 mm hole	Liquid/ Gas	1.70E-07	per metre per year	OGP
Piping 14″ to 18″	10 mm hole	Liquid/ Gas	3.05E-05	per metre per year	OGP
	25 mm hole	Liquid/ Gas	2.40E-06	per metre per year	OGP
	50 mm hole	Liquid/ Gas	3.60E-07	per metre per year	OGP
	>150 mm hole	Liquid/ Gas	1.70E-07	per metre per year	OGP
Piping 20″ to 24″	10 mm hole	Liquid/ Gas	3.04E-05	per metre per year	OGP
	25 mm hole	Liquid/ Gas	2.40E-06	per metre per year	OGP
	50 mm hole	Liquid/ Gas	3.60E-07	per metre per year	OGP
	>150 mm hole	Liquid/ Gas	1.60E-07	per metre per year	OGP
Piping 26″ to 48″	10 mm hole	Liquid/ Gas	3.04E-05	per metre per year	OGP
	25 mm hole	Liquid/ Gas	2.30E-06	per metre per year	OGP
	50 mm hole	Liquid/ Gas	3.60E-07	per metre per year	OGP
	>150 mm hole	Liquid/ Gas	1.60E-07	per metre per year	OGP
Pressure Vessel - Large Connection (> 6″)	10 mm hole	Liquid/ Gas	5.90E-04	per year	OGP
	25 mm hole	Liquid/ Gas	1.00E-04	per year	OGP
	50 mm hole	Liquid/ Gas	2.70E-05	per year	OGP
	>150 mm hole	Liquid/ Gas	2.40E-05	per year	OGP
Pump Centrifugal - Small Connection (up to 6″)	10 mm hole	Liquid	4.40E-03	per year	OGP
	25 mm hole	Liquid	2.90E-04	per year	OGP
	50 mm hole	Liquid	5.40E-05	per year	OGP
Pump Centrifugal - Large Connection (> 6″)	10 mm hole	Liquid	4.40E-03	per year	OGP
	25 mm hole	Liquid	2.90E-04	per year	OGP
	50 mm hole	Liquid	3.90E-05	per year	OGP
	>150 mm hole	Liquid	1.50E-05	per year	OGP
Compressor Reciprocating - Large Connection (> 6″)	10 mm hole	Gas	3.22E-02	per year	OGP
	25 mm hole	Gas	2.60E-03	per year	OGP
	50 mm hole	Gas	4.00E-04	per year	OGP
	>150 mm hole	Gas	4.08E-04	per year	OGP
Shell and Tube Heat Exchanger - Large Connection (> 6″)	10 mm hole	Liquid/Gas	1.20E-03	per year	OGP
	25 mm hole	Liquid/Gas	1.80E-04	per year	OGP
	50 mm hole	Liquid/Gas	4.30E-05	per year	OGP
	>150 mm hole	Liquid/Gas	3.30E-05	per year	OGP
Unloading Arm	10 mm hole	Liquefied Gas	4.00E-06*	per transfer operation	UK HSE (1)

(1) UK HSE, Failure Rate and Event Data for use within Risk Assessment, 28 June 2012.

Equipment	Release Scenario	Release Phase	Release Frequency	Unit	Reference
	25 mm hole	Liquefied Gas	4.00E-06*	per transfer operation	UK HSE (1)
	>150 mm hole	Liquefied Gas	7.00E-06	per transfer operation	UK HSE (1)
Riser	10 mm hole	Gas	7.2E-05	per year	OGP
	25 mm hole	Gas	1.8E-05	per year	OGP
	>150 mm hole	Gas	3.0E-05	per year	OGP
Diesel Storage Tank	10 mm hole	Liquid	1.6E-03	per year	OGP
	25 mm hole	Liquid	4.6E-04	per year	OGP
	50 mm hole	Liquid	2.3E-04	per year	OGP
	Rupture	Liquid	3.0E-05	per year	OGP
Unloading Hose	10 mm hole	Liquid	1.3E-05#	per hour	Purple Book (1)
	25 mm hole	Liquid	1.3E-05	per hour	Purple Book
	50 mm hole	Liquid	1.3E-05	per hour	Purple Book
	Rupture	Liquid	4.0E-06	per hour	Purple Book
LNG Storage Tank	10 mm hole	Liquid	3.3E-06!	per year	OGP
	25 mm hole	Liquid	3.3E-06!	per year	OGP
	50 mm hole	Liquid	3.3E-06!	per year	OGP
	Rupture	Liquid	2.5E-08	per year	OGP

*Notes: The leak frequency of unloading arm, presented in the UK HSE, has been evenly distributed into 10 mm and 25 mm hole sizes.

#Notes: The leak frequency of unloading hose, presented in the Purple Book, has been evenly distributed into 10 mm, 25 mm and 50 mm hole sizes.

!Notes: The leak frequency of LNG storage tank, presented in OGP, has been evenly distributed into 10 mm, 25 mm and 50 mm hole sizes.

5A.3.3 *QRA Study for Subsea Pipelines*

The release frequencies adopted in the QRA Study are summarised in the ***Table 5A.20*** and ***Table 5A.21***:

Table 5A.20 Summary of Release Frequency along the BPPS Pipeline

Pipeline Section	Trench Type	Anchor Impact (/km/yr)	Corrosion/ Defects (/km/yr)	Others (/km/yr)	Total (/km/yr)*
Jetty Approach to South of Soko Islands (X)	4	1.25E-05	1.18E-06	7.90E-07	2.30E-06
Southwest of Soko Islands (A)	5	1.25E-05	1.18E-06	7.90E-07	2.69E-06
Southwest of Fan Lau (B)	5	1.77E-04	1.18E-06	7.90E-07	1.99E-06
Southwest Lantau (C)	2	9.49E-05	1.18E-06	7.90E-07	5.85E-06
West of Tai O (D)	5	9.49E-05	1.18E-06	7.90E-07	1.98E-06
West of HKIA (E)	5	9.49E-05	1.18E-06	7.90E-07	1.98E-06
West of Sha Chau (F)	5	9.49E-05	1.18E-06	7.90E-07	1.98E-06
West of Lung Kwu Chau (G)	3	1.77E-04	1.18E-06	7.90E-07	1.99E-06

(1) Guidelines for Quantitative Risk Assessment, "Purple Book", 2005.

Pipeline Section	Trench Type	Anchor Impact (/km/yr)	Corrosion/ Defects (/km/yr)	Others (/km/yr)	Total (/km/yr)*
Lung Kwu Chau to Urmston Anchorage (H)	5	1.77E-04	1.18E-06	7.90E-07	1.99E-06
Urmston Road (I)	4	1.77E-04	1.18E-06	7.90E-07	1.99E-06
West of BPPS (J)	5/1	9.49E-05	1.18E-06	7.90E-07	1.98E-06

*The armour rock protection for the subsea pipeline and the associated protection factors were applied to reduce the anchor impact frequency. Refer to chapter

Table 5A.21 Summary of Release Frequency along the LPS Pipeline

Pipeline Section	Trench Type	Anchor Impact (/km/yr)	Corrosion/ Defects (/km/yr)	Others (/km/yr)	Total (/km/yr) *
Jetty Approach to South of Shek Kwu Chau (A)	4	1.32E-05	1.18E-06	7.90E-07	1.97E-06
South of Cheung Chau (B)	5	1.32E-05	1.18E-06	7.90E-07	1.97E-06
West Lamma Channel (C)	5	1.32E-05	1.18E-06	7.90E-07	1.97E-06
Alternative Shore Approach (D)	1	5.95E-05	1.18E-06	7.90E-07	1.98E-06

*The armour rock protection for the subsea pipeline and the associated protection factors were applied to reduce the anchor impact frequency.

5A.3.4 QRA Study for GRSs at the BPPS and the LPS

The release event frequencies were adopted from Hawksley [(1)], and summarised in ***Table 5A.22***.

Table 5A.22 Release Event Frequencies for the GRSs at the BPPS and the LPS

Equipment	Release Scenario	Release Phase	Release Frequency	Unit	Reference
Pipe size 600 mm to 750 mm	i) 10 & 25 mm hole	Liquid/ Gas	1.00E-07	per metre-year	Hawksley [(1)]
	ii) 50 & 100 mm hole	Liquid/ Gas	7.00E-08	per metre-year	Hawksley
	iii) Full bore rupture	Liquid/ Gas	3.00E-08	per metre-year	Hawksley
Pipe size 150 mm to 500 mm	i) 10 & 25 mm hole	Liquid/ Gas	3.00E-07	per metre-year	Hawksley
	ii) 50 & 100 mm hole	Liquid/ Gas	1.00E-07	per metre-year	Hawksley
	iii) Full bore rupture	Liquid/ Gas	5.00E-08	per metre-year	Hawksley

(1) Hawksley, J.L., *Some Social, Technical and Economic Aspects of the Risks of Large Plants*, CHEMRAWN III, 1984.

5A.4 *IGNITION PROBABILITY*

5A.4.1 *QRA Study for Marine Transit of the LNGC and the FSRU Vessel to The LNG Terminal*

As per the previous EIA Report that has been approved by the EPD (1), the immediate ignition probability for the collision scenarios was selected as 0.8; and the immediate ignition probability for the grounding scenarios was selected as 0.2 in the QRA Study.

5A.4.2 *QRA Study for The LNG Terminal*

The immediate ignition for the LNGCs, FSRU Vessel and the topside equipment of the Jetty was estimated based on offshore ignition scenarios No. 24 from OGP Ignition Probability Database (2).

For flammable liquids with flash point of 55 °C or higher (e.g. diesel, fuel oil etc.), a modification factor of 0.1 was applied to reduce the ignition probability as suggested in OGP (3).

The delayed ignition for various ignition sources is referred to Appendix 4.A of "Guidelines for Quantitative Risk Assessment, CPR 18E (Purple Book) (3).

5A.4.3 *QRA Study for the Subsea Pipelines*

As per the previous EIA Report that was approved by the EPD (4), the ignition probability for the subsea pipelines are given in ***Table 5A.23***.

Table 5A.23 Ignition Probability for the Subsea Pipelines

Release Case	Ignition Probability	
	Passing Vessels (1)	**Vessels in Vicinity (2)**
<25 mm	0.01	n/a
50 mm	0.05	n/a
100 mm	0.10	0.15
Half bore	0.20	0.30
Full bore	0.30	0.40

Note:

1: Values applied to passing vessels for all types of incidents, i.e. corrosion, others and anchor impact.

2: Values applied only to scenarios where the vessel causing pipeline damage due to anchor impact is still in the vicinity.

(1) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

(2) OGP, *Risk Assessment Data Directly, Report No. 434-6.1*, March 2010.

(3) *Guidelines for Quantitative Risk Assessment*, "Purple Book", 2005.

(4) ERM, EIA for *Liquefied Natural Gas (LNG) Receiving Terminal and Associated Facilities* (Register No.: AEIAR-106/2007), December 2006.

5A.4.4 *QRA Study for the GRSs at the BPPS and the LPS*

Table 5A.24 summarises the ignition probabilities adopted in the QRA Study for the GRS facilities, as per the previous EIA Report that was approved by the EPD and relevant authorities (1).

Table 5A.24 Ignition Probability for the GRS

	Immediate Ignition	Delayed Ignition 1	Delayed Ignition 2	Delayed Ignition Probability	Total Ignition Probability
Small leak	0.02	0.045	0.005	0.05	0.07
Large leak/ rupture	0.10	0.200	0.020	0.22	0.32

5A.5 EXPLOSION PROBABILITY

The probability of explosion given ignition is taken from Cox, Lees and Ang model (1) and summarised in ***Table 5A.25***.

Table 5A.25 Probability of Explosion Given Ignition

Leak Size (Release Rate)	Explosion Probability Given Ignition
Minor (< 1 kg s^{-1})	0.04
Major (1 – 50 kg s^{-1})	0.12
Massive (> 50 kg s^{-1})	0.30

5A.6 CONSEQUENCE END-POINT CRITERIA

The same consequence end-point criteria are applicable to the QRA Study for all Project components, and are summarised following sections.

5A.6.1 *Thermal Radiation of Jet Fire, Fireball and Pool Fire*

For thermal radiation impact, the associated fatality/ injury from fire events was estimated based on the following probit equation (2):

$$Y = -36.38 + 2.56 \ln (t\, I^{4/3})$$

where:

Y is the probit

I is the radiant thermal flux (W m^{-2})

t is duration of exposure (s)

The exposure time, t, is limited to maximum of twenty (20) seconds.

(1) Cox, Lees and Ang, *Classification of Hazardous Locations*, IChemE.

(2) TNO, *Methods for the Determination of Possible Damage to People and Objects Resulting from Releases of Hazardous Materials (The Green Book)*, Report CPR 16E, The Netherlands Organisation of Applied Scientific Research, Voorburg, 1992.

Table 5A.26 Levels of Harm for 20 seconds Exposure to Heat Fluxes

Incident Thermal Flux ($kW\ m^{-2}$)	Fatality Probability for 20 s Exposure	Equivalent Fatality Probability for Area between Radiation Flux Contours
9.8	1.0%	
		17.0%
19.5	50.0%	
		77.0%
28.3	90.0%	
		97.0%
35.5	99.9%	

5A.6.2 *Flash Fire*

With regard to a flash fire, the criterion chosen is that a 100% fatality was adopted for any person outdoors within the flash fire envelope, which was conservatively selected as 0.85 of the LFL.

5A.6.3 *Overpressure*

The fraction of people in fatality given an explosion is taken from the Purple Book, and summarised in ***Table 5A.27***.

Table 5A.27 Effect of Overpressure

Explosion Overpressure	Fraction of People in Fatality	
	Indoor	Outdoor
> 0.3 barg	1.000	1.000
> 0.1 to 0.3 barg	0.025	0.000

5A.6.4 *Fireball*

The flammable mass for fireball modelling was conservatively estimated by the initial flow rate continuing for ten (10) seconds even though the initial release rate decreases rapidly in case of a pipeline full-bore rupture scenario.

The fatality rate within the fireball diameter are assumed be 100%.

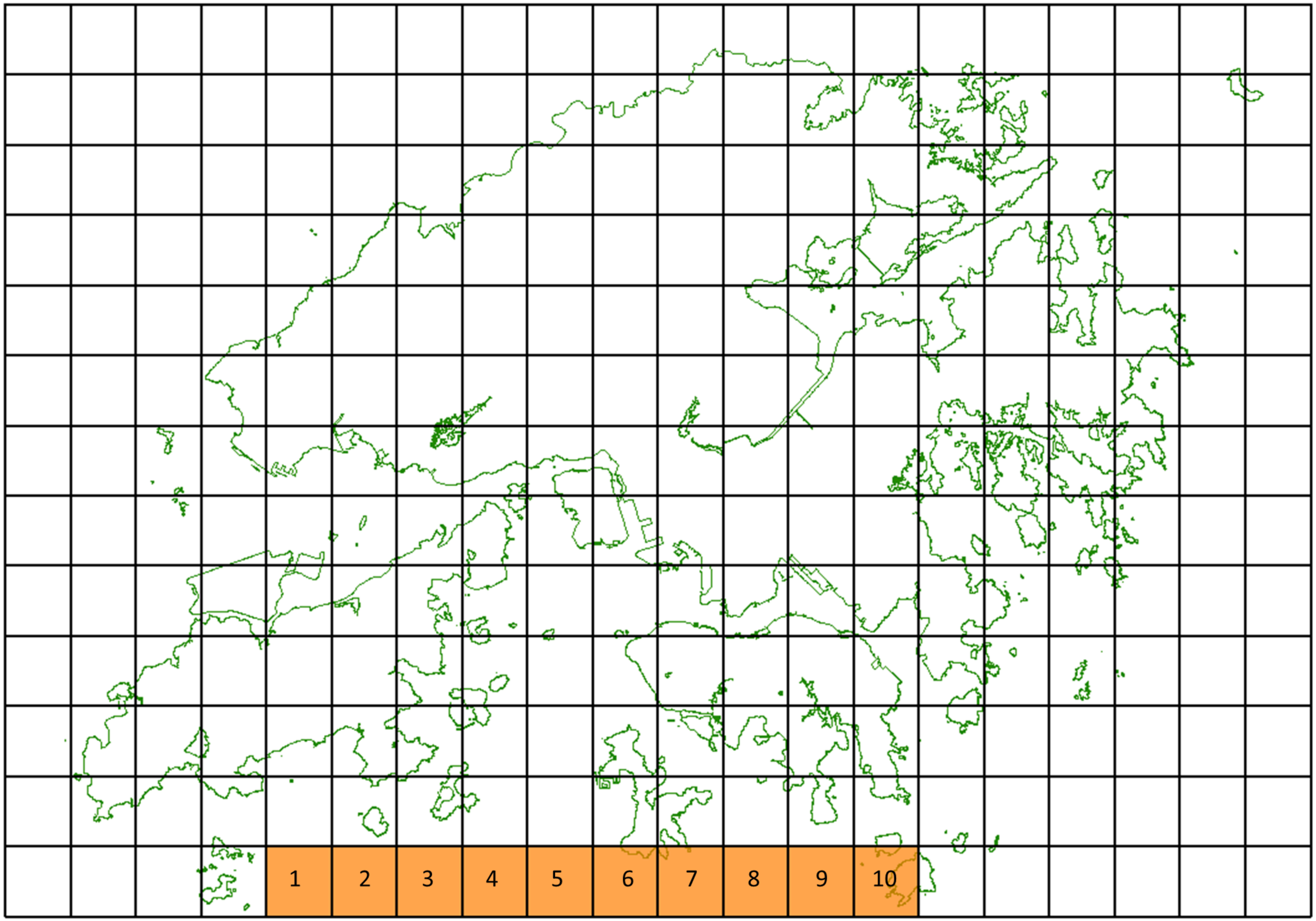

Figure 5A.1

Grid Cell Scheme for LNGC/FSRU Vessel Transit and the Offshore Terminal

Environmental Resources Management

ERM

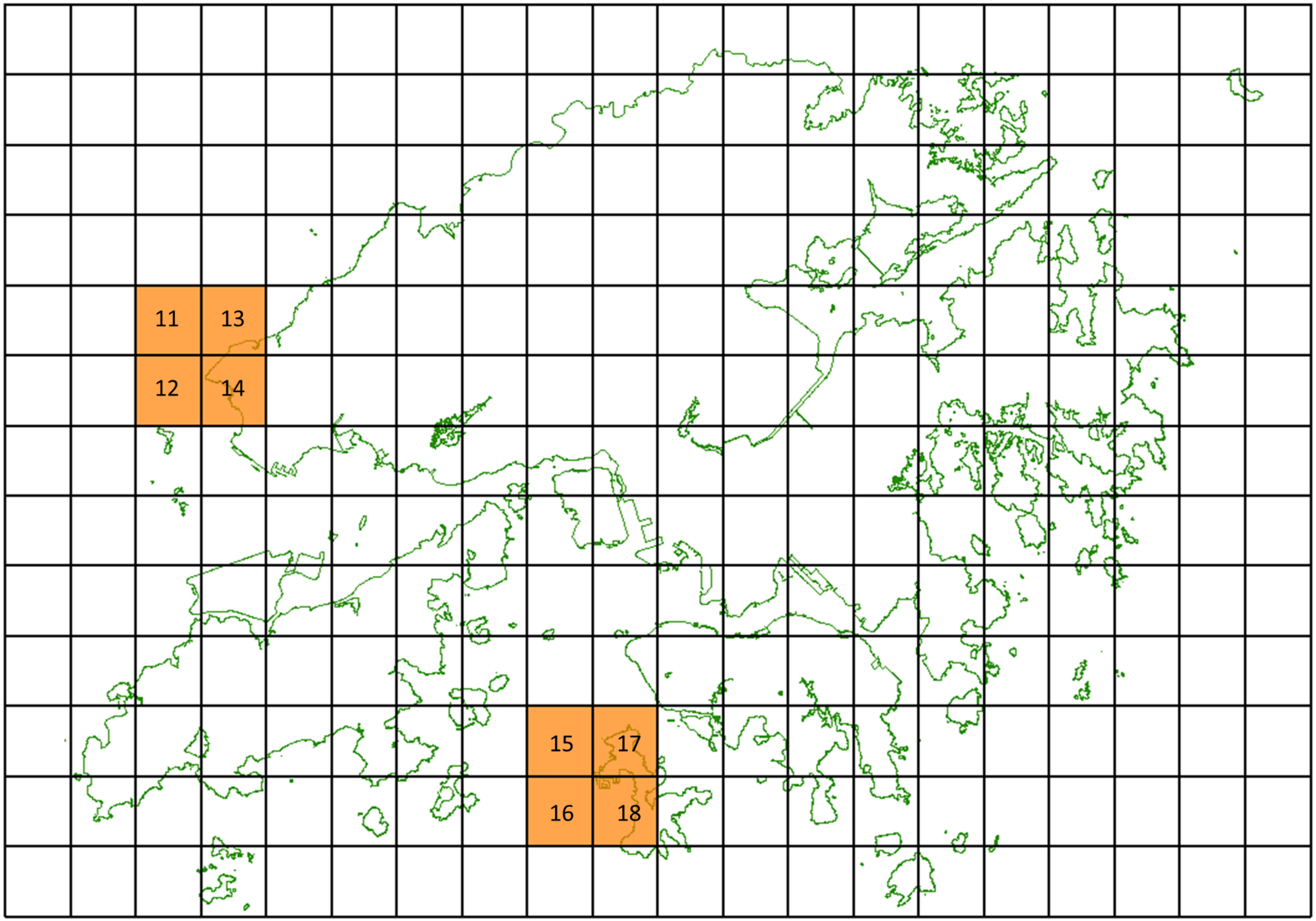

Figure 5A.2

Grid Cell Scheme for the Proposed GRSs at the BPPS and LPS

Environmental Resources Management

ERM