Prepared by

Ramboll Hong Kong Limited

ENVIRONMENTAL IMPACT ASSESSMENT STUDY FOR SAI O TRUNK SEWER SEWAGE PUMPING STATION

APPENDIX 9.2
REVIEW OF HAZARD TO LIFE IMPACT FROM MOSWTW

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1. Introduction

1.1 Background

A new sewage pumping station, the Sai O Trunk Sewer Sewage Pumping Station (hereafter referred to as the "Project") is proposed at the north of Sai O near Nai Chung, with a capacity of about 20,600m^3 per day for coping with the sewerage needs of both existing and future developments. The Project is part of Public Works Programme Item 4125DS – Tolo Harbour Sewerage of Unsewered Areas, Stage II, which originates from the findings of the Study "Review of North District and Tolo Harbour Sewerage Master Plan" completed in 2002. The location of the proposed development is shown in **Figure 1**.

The Project consists of Designated Project (DP) under Item F3, Part I, Schedule 2 of the Environmental Impact Assessment Ordinance (EIAO). An application for an Environmental Impact Assessment (EIA) Study Brief under section 5(1)(a) of the EIAO was made to Environmental Protection Department (EPD) and the EIA Study Brief No. ESB-281 /2014 issued under the EIAO. According to the Study Brief, the proposed sewage pumping station falls within the 1km Potentially Hazardous Installation (PHI) Consultation Zone of Ma On Shan Water Treatment Works (MOSWTW). A study is required to review the risks from MOSWTW to the Project, in order to determine if risk to life is a key issue with respect to the Hong Kong Risk Guidelines.

1.2 Report Scope and Objectives

This Hazard Assessment (HA) presents the analyses and findings in reviewing the risks of the Project in its construction and operation periods. This HA aims to achieve the objectives as set out in Section 3.4.5 of the EIA Study Brief:

"3.4.5 Hazard to Life

3.4.5.1 The Applicant shall follow the criteria for evaluating hazard to life as stated in Annex 4 of the TM.

3.4.5.3 The proposed works also falls within the 1km Potentially Hazardous Installation (PHI) Consultation Zone of Ma On Shan Water Treatment Works (MOSWTW). The Applicant shall conduct a review of the risks from MOSWTW to the Project and assess if risk to life is a key issue with respect to Hong Kong Risk Guidelines given in Annex 4 of the EIAO-TM. Hazard assessment including a Quantitative Risk Assessment (QRA) for MOSWTW shall be conducted if, and only if, risk to life is a key issue· with respect to Hong Kong Risk Guidelines following the requirements in Section 12.1 of EIAO-TM. If a QRA for MOSWTW is required, the detailed technical requirements shall follow Appendix G."

Appendix G of the EIA Study Brief:

1. *"The Applicant shall investigate methods to eliminate and/or minimize risks from town gas/chlorine. The Applicant shall carry out hazard assessment to evaluate potential hazard to life during construction and operation stages of the Project. The hazard assessment shall include but not limited to the following:*

i. *Identify hazardous scenarios associated with town gas/chlorine, and then determine a set of relevant scenarios to be included in a Quantitative Risk Assessment (QRA);*

ii. *Execute a QRA of the set of hazardous scenarios determined in (i), expressing population risks in both individual and societal terms;*

iii. *Compare individual and societal risks with the criteria for evaluating hazard to life stipulated in Annex 4 of the TM; and*

iv. *Identify and assess practicable and cost-effective risk mitigation measures.*

2. *The methodology to be used in the hazard assessment should be consistent with previous studies having similar issues*."

1.3 Study Approach

This paper evaluates the risks of MOSWTW to the Project by reviewing the previous hazard assessments of the MOSWTW. Hence, the previous hazard assessment's hazard scenarios, frequency assessments and consequence assessments are directly adopted in this study. Finally, the risk levels of the Project posed by the MOSWTW is evaluated by a risk summation and compared with the risk criteria.

1.4 Risk Acceptance Criteria

As stipulated in Annex 4 of the EIAO-TM, the risk guidelines comprise two measures shown as follows:

i. **Individual Risk**: the maximum level of off-site individual risk should not exceed 1 x 10^{-5} / year, i.e. 1 in 100,000 per year.

ii. **Societal Risk**: it can be presented graphically as in **Figure 2**. The Societal Risk Guideline is expressed in terms of lines plotting the frequency (F) of N or more fatalities in the population from accidents at the facility of concern. There are three regions as described below:

- **Acceptable** where the risk is so low that no action is necessary;

- **Unacceptable** where the risk is high enough that it should be reduced regardless of the cost or else the project of concern should not proceed; and

- **ALARP** (As Low As Reasonably Practicable) where the risk associated with the facility of concern should be reduced to a level "as low as reasonably practicable", in which the priority of measures is established on the basis of practicality and cost to implement versus the risk reduction achieved.

1.5 Review of Previous Hazard Assessment of MOSWTW

The previous hazard assessment that studies the potential risks associated with the MOSWTW is the "Final report of Hazard Assessment on Ma On Shan Water Treatment Works" [1] (hereafter as HA2018).

Since HA2018 is the most recently approved hazard assessment of the MOSWTW, the methodologies of HA2018 will form the basis when reviewing the risks in the current study. The methodology adopted in the 2001 Reassessment Reports [1] will also be used as a reference as the reports are the latest methodology commonly accepted for assessing a Water Treatment Works.

1.6 **Cases to be Considered**

As the main objective of this hazard assessment is to review the risks from the MOSWTW to the Project, two cases will be considered to demonstrate the changes in risk level induced by the Project as below. Based on current information, the construction of the Sai O SPS will commence in 2022 and operation year will be in 2024. To be conservative, the operation assessment year is taken as 2025.

Construction case (2022) – to assess the risks due to the presence of construction workers within the site; and

Operation case (2025) – to assess the risks due to the presence of the proposed pumping station.

2. Description of MOSWTW

2.1 Location

MOSWTW is located between two ridges to the southeast and northwest directions. The elevation of the ridges is up to 150 mPD and higher. The local topographic feature acts as a natural barrier to prevent discharge of chlorine cloud in case of leak incidents. Moreover, extensive vegetation coverage helps to stop dispersion of chlorine further downstream.

Facilities relevant to chlorine transport, storage and use include:

- Chlorine building is equipped with a single-pass scrubber system, mechanical ventilation system, chlorination facilities and chlorine store.
- 500m of internal access road provides access to the chlorine store for delivery of chlorine stock.

2.2 Operation Data

The operation data are extracted from HA2018 [1] and summarized in Table 1 below.

Table 1 Operation Data of MOSWTW

Parameter	Value
Maximum design throughput	227 MLD
Designed chlorine dosage	2.68 mg/L
Average chlorine dosage	3.58 mg/L
Type of container in use	1 tonne drum
Maximum storage quantity	59 drums
Maximum number of drums per delivery	6 drums per truck
Scrubber system	Single pass
Length of onsite chlorine delivery route	0.5km

2.3 Review of Current Status of MOSWTW

It is understood the MOSWTW is undergoing a modification work for the installation of an on-site chlorine generation (OSCG) system, which is anticipated to be completed by end 2021. With that new technology, chlorine gas can be generated on-site according to the demand for consumption. With removal of the bulk storage of the liquid chlorine upon satisfactory installation of OSCG system, the risks associated with the existing operation of the MOSWTW would be avoided.

Since the OSCG system is not yet completed and the future arrangement of the storage of liquid chlorine is yet unknown, as a conservative approach for the purpose of this EIA study, a hazard review was conducted considering the worst-case scenario that the operation conditions of MOSWTW adopted in HA2018 remains unchanged during the construction and operation of the Project. The assumptions, failure cases, frequencies and consequences adopted in HA2018 is used as the basis in this study.

The results of hazard review are presented in this report.

3. Project Data

3.1 Population Data

3.1.1 The Proposed Sewage Pumping Station

As per the information given by the Project team, the construction of the Project would commence around 2022 and the Project will come into operation around 2024. To be conservative, the operation assessment year is taken as 2025. For construction, a conservative number of 30 people (including engineers and construction workers) in day time is assumed. The proposed sewage pumping station will be an unmanned station during operation. Regular maintenance is assumed to be carried out twice a year and about 8 staff will be involved in maintenance. For simplicity, it is conservatively assumed that the maintenance team is present in the pumping station in the day time for the whole year similar to construction workers.

The population of the proposed sewage pumping station in the construction and operation phase are summarized in **Table 3**. In this assessment, it is assumed the populations of the proposed sewage pumping station are at a height of 1m.

3.1.2 Temporal Variation

In order to reflect the temporal changes in the population within a week, the population data is presented in different time modes. HA2018 recommended to adopt 5 time modes to present the population data similar to the 2001 Reassessment Reports [2]. The time modes are "peak", "jammed peak", "working day", "weekend day" and "night". Their distribution is listed in **Table 2** below.

Table 2 Different Time Periods and Distributions

Time Period	Mon – Fri	Sat	Sun	% Distribution
Peak	18.75 hr	3.75 hr	0 hr	13.39%
Jammed Peak	1.25 hr	0.25 hr	0 hr	0.89%
Working Day	40 hr	4 hr	0 hr	26.19%
Weekend Day	0 hr	4 hr	12 hr	9.52%
Night	60 hr	12 hr	12 hr	50.00%

The temporal changes of the construction workers and maintenance staff of the proposed sewage pumping station are provided in **Table 3**.

Table 3 Population of Proposed Sewage Pumping Station

ID	Description	Type of Building / Site	Population	Height (m)	Night	Jammed Peak	Peak	Weekend Day	Working Day	Indoor Ratio	Vulnerability Factor
PD1	Construction Worker	Construction Site	30	1	0%	100%	100%	50%	100%	0%	1
PD2	Pumping Station Maintenance Staff	Construction Site	8	1	0%	100%	100%	50%	100%	0%	1

3.2 Meteorological Information

The meteorological conditions affect the consequence of release and hence risk outcomes, in particular the wind direction, speed and stability, which influences the direction and degree of turbulence of gas dispersion. Meteorological data from the Hong Kong Observatory Sha Tin weather station was adopted in HA2018. For consistency, the same set of meteorological data as tabulated in **Table 4** is adopted in this study.

Table 4 Statistic of Frequencies of Different Weather Categories

Direction	Day Time			Night Time			Total
	B2	C4	D3	D3	E3	F1.5	
15-44	0.0452	0.0181	0.0207	0.0262	0.016	0.0355	0.1617
45-74	0.0353	0.0175	0.0227	0.0328	0.0189	0.0363	0.1635
75-104	0.0288	0.0171	0.0184	0.0261	0.0149	0.0375	0.1428
105-134	0.0237	0.0175	0.0139	0.0176	0.0126	0.0249	0.1102
135-164	0.0115	0.0069	0.0068	0.005	0.0031	0.0111	0.0444
165-194	0.0081	0.0048	0.0047	0.0022	0.003	0.0159	0.0387
195-224	0.0159	0.0141	0.0151	0.0094	0.0079	0.0345	0.0969
225-254	0.0097	0.02	0.0234	0.0136	0.0151	0.031	0.1128
255-284	0.0014	0.0021	0.0027	0.0012	0.0014	0.0092	0.018
285-314	0.0012	0.0002	0.0011	0.0008	0.0001	0.0082	0.0116
315-344	0.0022	0.0017	0.0039	0.0051	0.002	0.0116	0.0265
345-14	0.01	0.0055	0.0113	0.0175	0.0071	0.0219	0.0733
All	**0.193**	**0.1255**	**0.1447**	**0.1575**	**0.1021**	**0.2776**	**1.0004**

To facilitate the calculation, the frequencies are further divided into day time and night time by normalizing each frequency using the sum of frequencies in day and night as shown in the tables below.

Table 5 Day Time Statistic of Frequencies of Different Weather Categories

Direction	Day Time			Total
	B2	C4	D3	
15-44	0.0976	0.0391	0.0447	0.1813
45-74	0.0762	0.0378	0.0490	0.1630
75-104	0.0622	0.0369	0.0397	0.1388
105-134	0.0512	0.0378	0.0300	0.1190
135-164	0.0248	0.0149	0.0147	0.0544
165-194	0.0175	0.0104	0.0101	0.0380

Direction	Day Time			Total
	B2	C4	D3	
195-224	0.0343	0.0304	0.0326	0.0974
225-254	0.0209	0.0432	0.0505	0.1146
255-284	0.0030	0.0045	0.0058	0.0134
285-314	0.0026	0.0004	0.0024	0.0054
315-344	0.0047	0.0037	0.0084	0.0168
345-14	0.0216	0.0119	0.0244	0.0579
All	**0.4167**	**0.2709**	**0.3124**	**1.000**

Table 6 Night Time Statistic of Frequencies of Different Weather Categories

Direction	Night Time			Total
	D3	E3	F1.5	
15-44	0.0488	0.0298	0.0661	0.1446
45-74	0.0611	0.0352	0.0676	0.1638
75-104	0.0486	0.0277	0.0698	0.1461
105-134	0.0328	0.0235	0.0464	0.1026
135-164	0.0093	0.0058	0.0207	0.0357
165-194	0.0041	0.0056	0.0296	0.0393
195-224	0.0175	0.0147	0.0642	0.0964
225-254	0.0253	0.0281	0.0577	0.1111
255-284	0.0022	0.0026	0.0171	0.0220
285-314	0.0015	0.0002	0.0153	0.0169
315-344	0.0095	0.0037	0.0216	0.0348
345-14	0.0326	0.0132	0.0408	0.0866
All	**0.2932**	**0.1901**	**0.5168**	**1.000**

4. Hazard Identification and Frequency Assessment

4.1 Chlorine Release Scenarios from Previous Assessment

Internal release and external release scenarios were considered in HA2018. Internal release cases are the releases of chlorine to the atmosphere through the scrubber and ventilation systems within the chlorine storage building. Since the second containment based on a "Contain and Absorb System" is available, the release rates to the surrounding environment can be reduced.

External release cases are referred to the releases directly from the chlorine drums either due to car accidents on the access road or due to earthquake and aircraft crash.

The frequencies of release scenarios were estimated from historical failure data of on-site transport, storage and use of chlorine of the Water Treatment Works in Hong Kong.

As mentioned in **Section 2.3**, the operation conditions of MOSWTW adopted in HA2018 is assumed remaining unchanged as worse-case consideration. The chlorine release scenarios as well as the event frequencies in HA2018 are directly adopted in this hazard review. The release scenarios and the corresponding frequencies are summarized in **Annex B**.

5. Consequence Assessment

5.1 Overview

The dispersion of chlorine in HA2018 was based on a software package "WHAZAN" (World Bank Hazard Analysis), which is a computer model for predicting dense cloud dispersion.

The results of consequence modelling data were available in form of Lethal Dose (LD) LD03, LD50 and LD95 contours. The contours were presented by the maximum downwind and crosswind distances.

Factors including escape probability, effective fatality probability and chlorine cloud height are considered in the consequence assessment. Since the model is a flat terrain model, topographical effects are not taken into account.

5.2 Gas Dispersion and LD Contours

5.2.1 LD Contours

LD contours for outdoor population of fatality probability of LD03, LD50 and LD95 were predicted using WHAZAN in HA2018. The maximum downwind and crosswind distances are extracted from the previous reports and reproduced in **Annex C**. The consequence data will be directly used in this hazard assessment to evaluate the change of risks as a result of the presence of the proposed sewage pumping station.

5.2.2 Release Locations

Following HA2018, the chlorine release location is assumed at the centre of chlorine store and is set at 844600, 831828 in HK Grid at an elevation of 32mPD.

5.2.3 Wind Directions

12 wind directions are used in HA2018 as the minimum number of wind directions. For "wind smoothing" purpose, the cloud dispersion contours are rotated every 10° in wind direction using the closest wind direction contour through rotational transformation. Depending on the smoothness of individual risk contours in the verification exercise, a smaller wind rotation angle may be adopted for satisfactory output.

5.2.4 Rationalization of LD Contours

In this study, the main purpose is to review whether the risk to the Project posed by the MOSWTW is a major concern.

Since the Project Site is around 760m from the assumed chlorine release location of MOSWTW. By referring to the downwind distance of the LD contours in **Annex C**, it is obvious that only the contours due to 1 tonne instantaneous release and 7 tonne instantaneous release (hence event ID. E19, E28, E34 and E35) are able to reach the Project Site. Therefore, only these four events are further considered in the risk summation in the later sections.

Moreover, construction work and routine maintenance will only be carried out during day time. Wind speed and stability in night time including D3, E3 and F1.5 are therefore not further considered.

The shapes of the LD contours were not illustrated nor the downwind distances at which the maximum crosswind distances occur were presented in HA2018. As a conservative approach, the LD contours in this assessment are therefore plotted in rectangular shapes using the maximum downwind and crosswind distances. The LD contours, which rotated in every 30 degrees, are illustrated in **Annex D**.

6. Risk Assessment

6.1 Risk Summation

By combining the population data, meteorological data, results of frequency estimation and consequence analysis, risk levels due to the presence of MOSWTW, have been characterised in terms of individual risk (presented in the form of risk contours) and societal risk (presented in the form of a F-N curve).

The societal risks of the Project in the construction phase and operation phase were calculated using a risk summation method. An example of the calculation of the Event ID E19 is shown in **Annex D**.

6.2 Results of Individual Risk

The individual risk represents the risk of the MOSWTW itself, hence the introduction of the Project and other population within its Consultation Zone does not induce any change to the individual risk of the MOSWTW.

As it is confirmed that the operation data of the MOSWTW has remained the same since HA2018, the individual risk of the MOSWTW is identical to that of HA2018 and reproduced in **Figure 3**.

It is clearly shown in **Figure 3** that the individual risk contour can hardly affect the population in the proposed pumping station.

6.3 Results of Societal Risk

6.3.1 Project Site Only

The societal risks of the Project site in the construction phase and operation phase calculated using a risk summation by considering the effects of Event ID E19, E28, E34 and E35 are shown in **Table 7** and **Figure 4**.

Societal risk can also be represented in the form of Potential Loss of Life (PLL). It expresses the risk to the population as a whole and for each scenario and its location. The PLL is an integrated measure of societal risk obtained by summing the product of each F-N pair:

$$\mathrm{PLL} = f_1 N_1 + f_2 N_2 + \cdots + f_n N_n$$

The PLLs of the Project Site in the construction phase and operation phase are 1.12×10^{-7} no. of fatality per year and 3.11×10^{-8} no. of fatality per year respectively.

Table 7 F-N Data of Project Site Only

Construction Case		Operation Case	
No. of Fatality (N)	Frequency (F)	No. of Fatality (N)	Frequency (F)
1	4.18E-08	1	4.18E-08
2	3.38E-08	2	2.43E-11
3	1.68E-08		
4	2.43E-11		

6.3.2 Overall Societal Risk

The societal risks presented in **Section 6.3.1** are calculated using the same methodology, event frequencies and consequence results in HA2018. Therefore, the societal risks of the Project Site can be summed up with the societal risk result of HA2018 to estimate the overall risk level.

The combined societal risks of the Construction Case and Operation Case are shown in **Table 8** and illustrated in **Figure 5** and **Figure 6**.

From **Table 8**, it can be observed that the frequencies of the Project site only contribute insignificant portions (around 1.1% to 2.2%) to the corresponding frequencies of the combined societal risks. This is due to the Project's frequencies (in the range of 10^{-9} to 10^{-8} per year) are in two to three orders of magnitude lower than the combined societal risk's frequencies (1×10^{-6} to 1×10^{-5} per year).

It can also be seen in **Figure 5** and **Figure 6** that the changes of risk levels are insignificant in terms of F-N curve after considering the Project in its construction phase and operation phase in the combined societal risks. The F-N curves (gold line in construction case and dark orange line in operation case) overlap with the baseline FN curve (black dashed line). One should note that the combined societal risks are within the ALARP region mainly due to the background population instead of due to the induction of the Project itself.

With the additional population of the Project, the increase in societal risk is negligible in both construction and operation phase. It is therefore suggested that the risks from the MOSWTW to the Project is not a major concern.

Table 8 Combined Societal Risks

Baseline FN of HA2018		Combined FN (HA2018 and Construction Case)			Combined FN (HA2018 and Operation Case)		
No. of Fatality (N)	Frequency (F)	No. of Fatality (N)	Frequency (F)	% of F of Project Site to F of Combined FN	No. of Fatality (N)	Frequency (F)	% of F of Project Site to F of Combined FN
1	3.70E-06	1	3.74E-06	1.12%	1	3.74E-06	1.12%
2	1.54E-06	2	1.57E-06	2.15%	2	1.54E-06	
3	1.18E-06	3	1.20E-06	1.41%	3	1.18E-06	
4	1.15E-06	4	1.15E-06		4	1.15E-06	
5	1.15E-06	5	1.15E-06		5	1.15E-06	
6	1.15E-06	6	1.15E-06		6	1.15E-06	
7	1.11E-06	7	1.11E-06		7	1.11E-06	
8	1.11E-06	8	1.11E-06		8	1.11E-06	
9	1.10E-06	9	1.10E-06		9	1.10E-06	
10	1.09E-06	10	1.09E-06		10	1.09E-06	
20	9.45E-07	20	9.45E-07		20	9.45E-07	
30	8.35E-07	30	8.35E-07		30	8.35E-07	
40	7.62E-07	40	7.62E-07		40	7.62E-07	
50	7.34E-07	50	7.34E-07		50	7.34E-07	
60	6.90E-07	60	6.90E-07		60	6.90E-07	

Baseline FN of HA2018		Combined FN (HA2018 and Construction Case)			Combined FN (HA2018 and Operation Case)		
No. of Fatality (N)	Frequency (F)	No. of Fatality (N)	Frequency (F)	% of F of Project Site to F of Combined FN	No. of Fatality (N)	Frequency (F)	% of F of Project Site to F of Combined FN
70	6.50E-07	70	6.50E-07		70	6.50E-07	
80	6.10E-07	80	6.10E-07		80	6.10E-07	
90	5.50E-07	90	5.50E-07		90	5.50E-07	
100	5.00E-07	100	5.00E-07		100	5.00E-07	
200	1.06E-07	200	1.06E-07		200	1.06E-07	
300	1.87E-08	300	1.87E-08		300	1.87E-08	
400	4.70E-09	400	4.70E-09		400	4.70E-09	
480	1.00E-09	480	1.00E-09		480	1.00E-09	

7. Conclusion

A review of the risks posed by the MOSWTW to the Project has been carried out. The societal risk results showed that the increases in risk levels due to the construction phase and operation phase of the Project were insignificant.

The results suggested that, because of an insignificant increase of population induced by the Project and a relatively far distance of the Project Site from the MOSWTW, risk to life is not a key issue with respect to the Hong Kong Risk Guidelines given in Annex 4 of the EIAO-TM. Therefore, a full QRA for the MOSWTW is not required.

8. References

[1] Final Report of Hazard assessment on Ma On Shan Water Treatment Works, 188563/B&V/026/Issue 3, August 2018.

[2] Reassessment of Chlorine Hazard for Eight Existing Water Treatment Works, ERM, 2001.

Figures

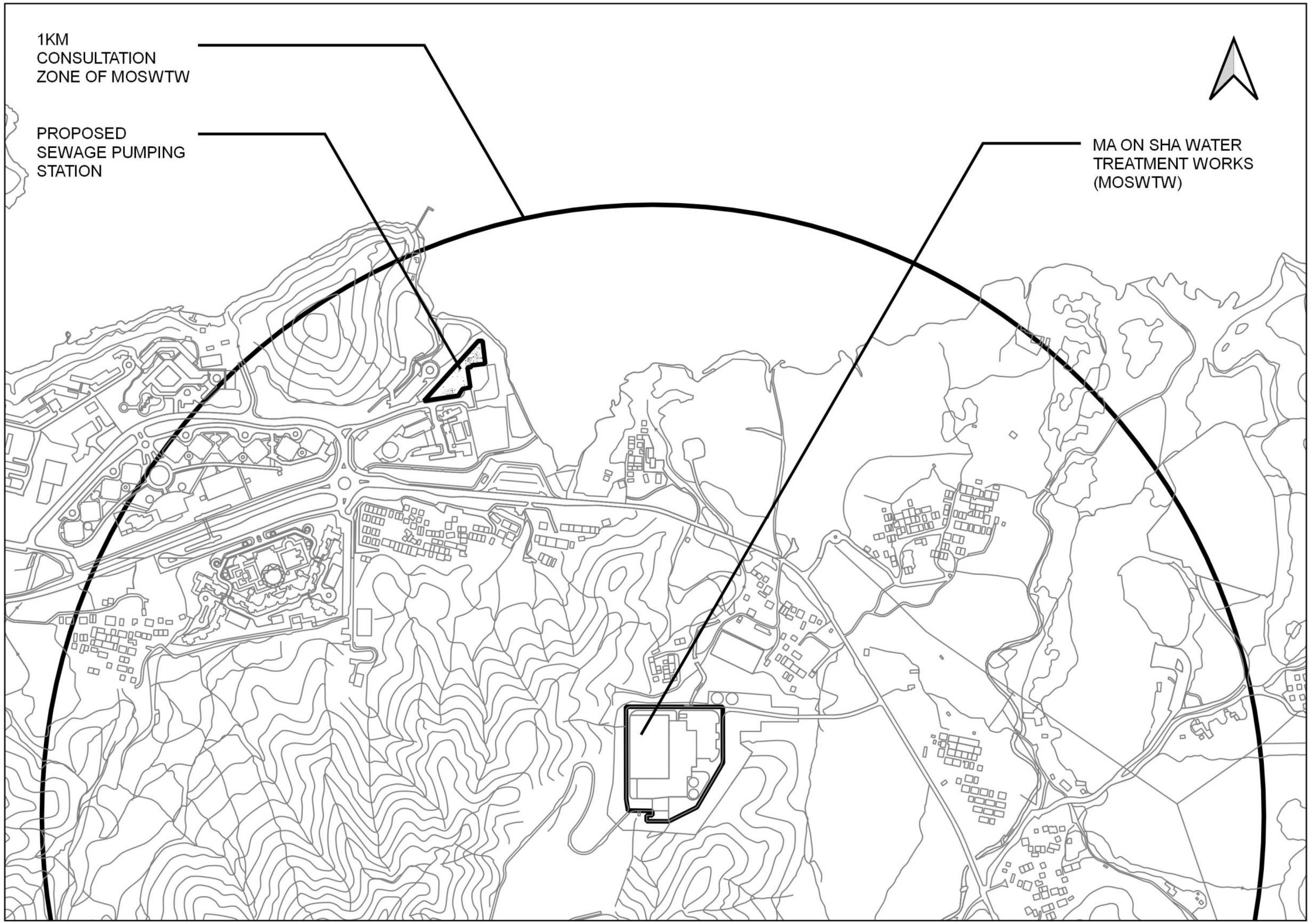


Figure 1 Location of the Project Site

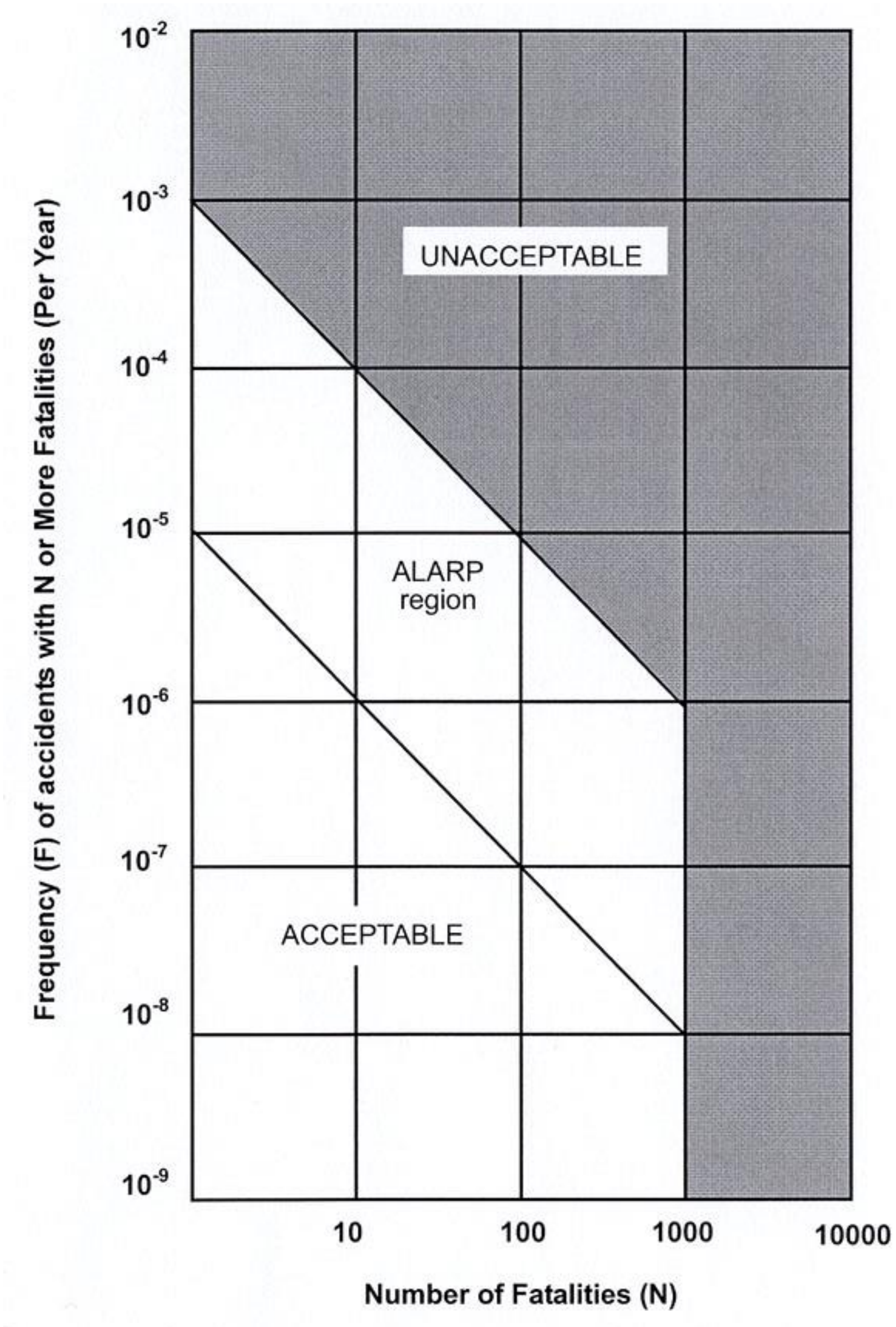


Figure 2 Societal Risk Guideline (EIAO-TM)

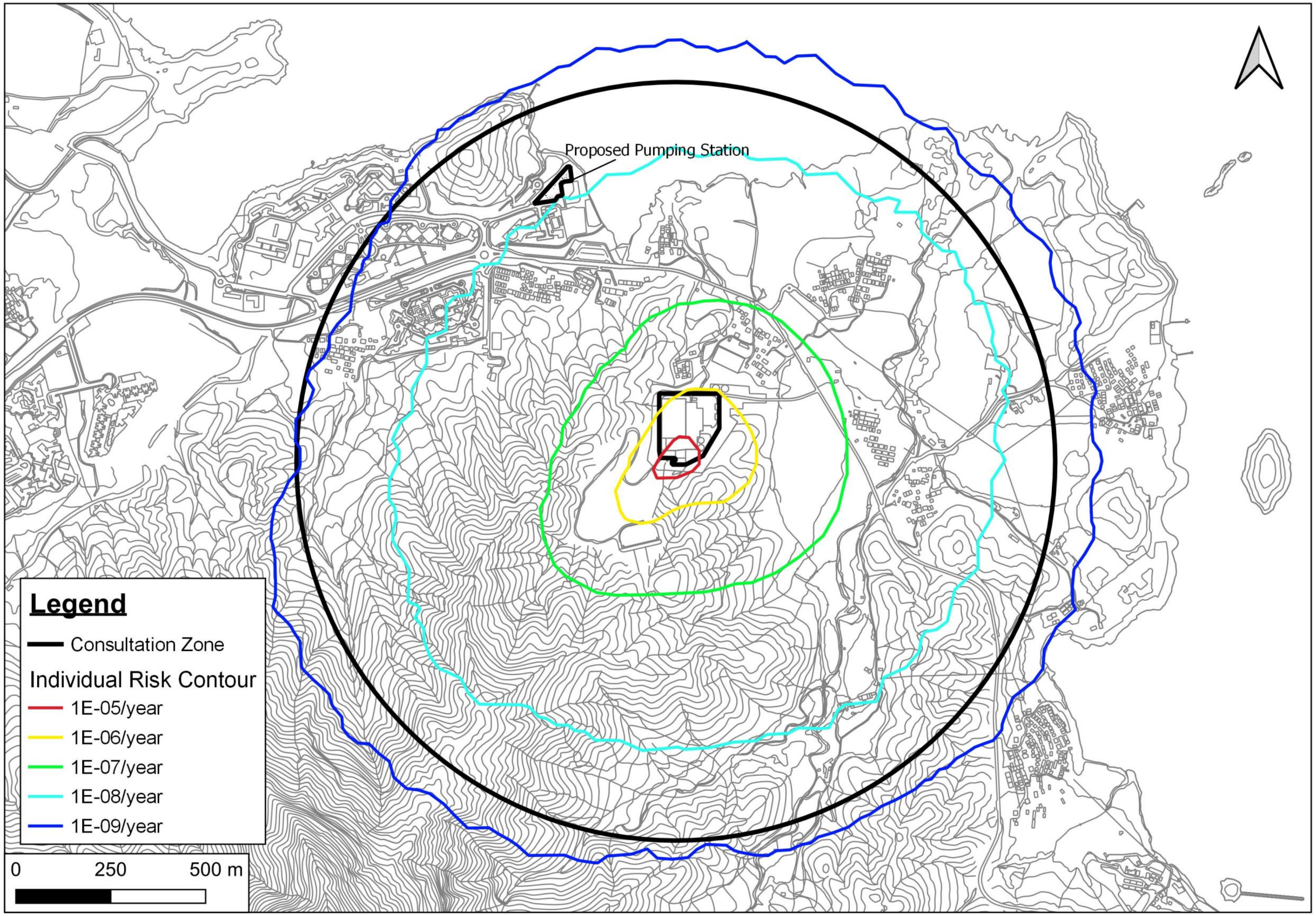


Figure 3 Individual Risk of MOSWTW

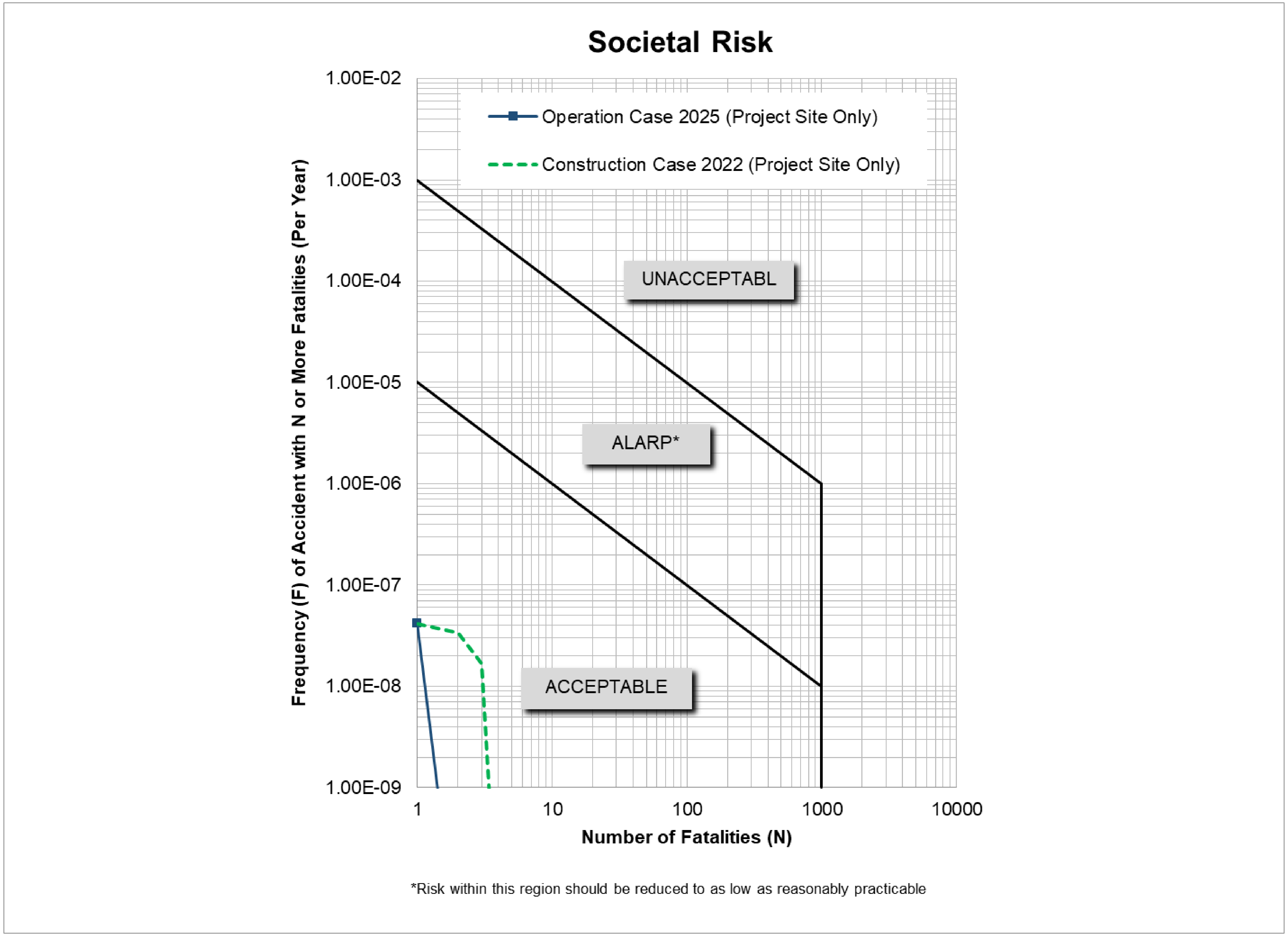


Figure 4 Societal Risks of Project Site Only

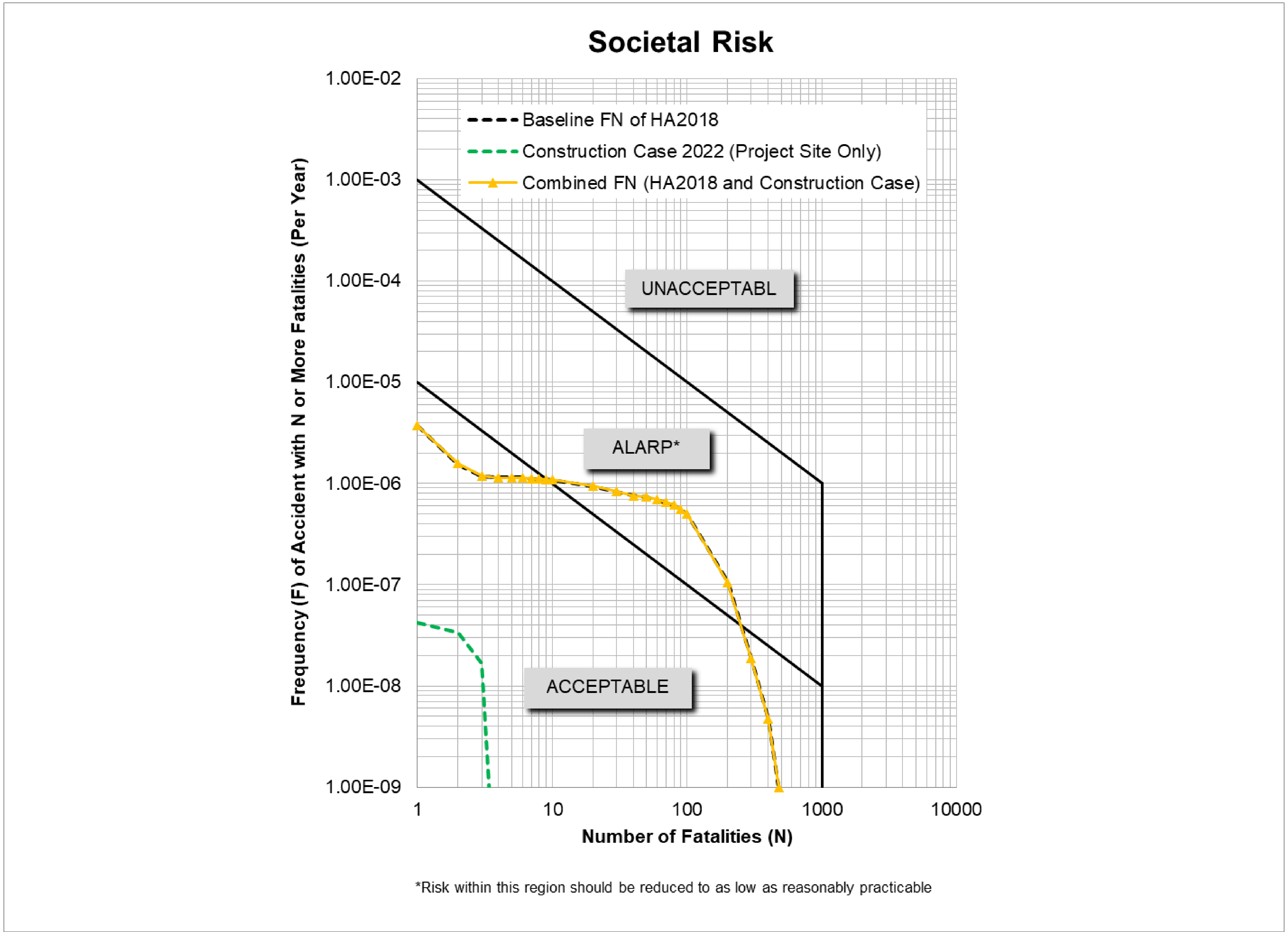


Figure 5 Combined Societal Risk (Construction Case 2022)

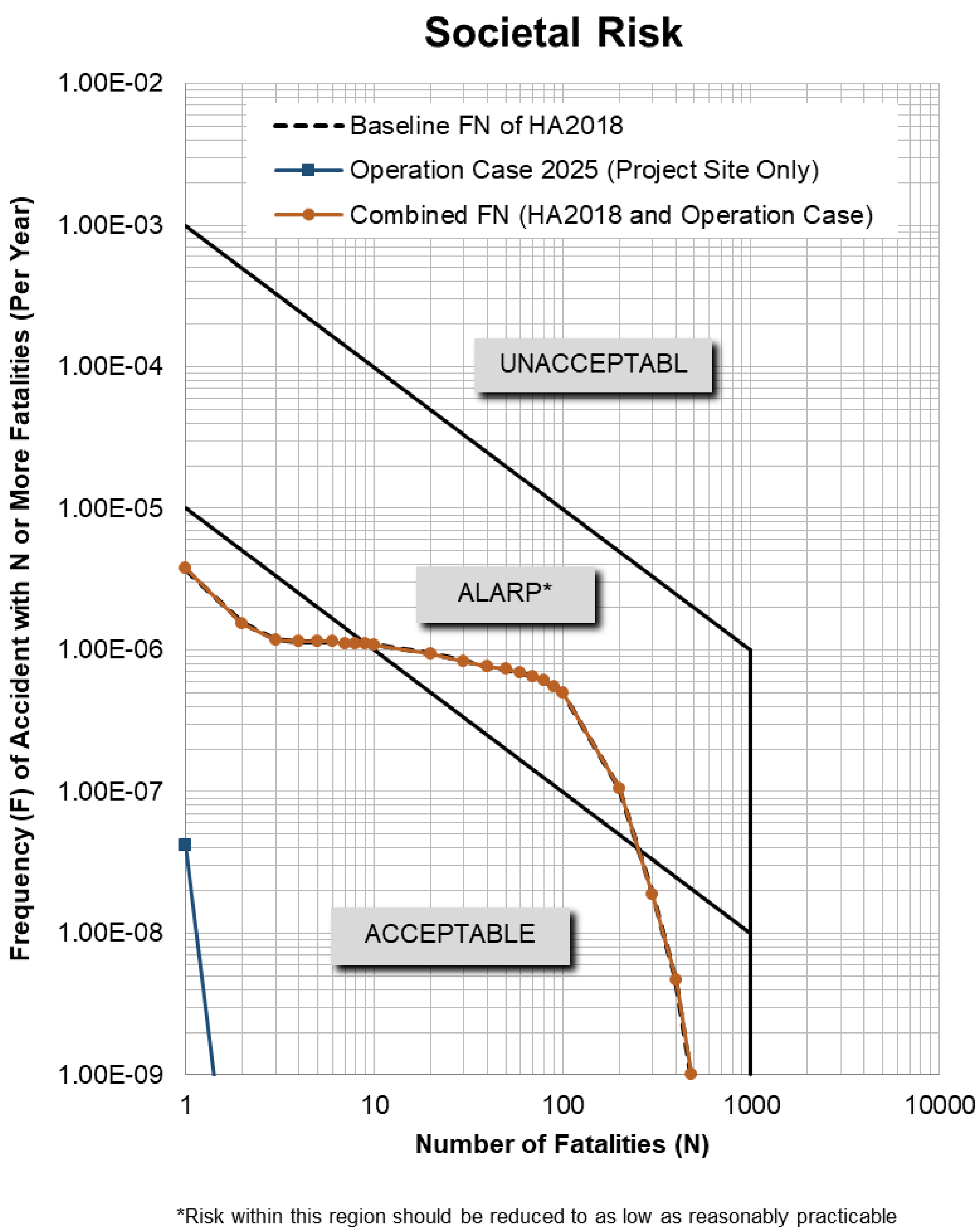


Figure 6 Combined Societal Risk (Operation Case 2025)

Annex A:
Summary of Hazard Scenarios and Frequencies

Table A1 Summary of Hazard Scenarios and Frequencies

Internal Release					
Event ID	**Initial Event**	**Scrubber available**	**Ventilation shut down**	**Frequency of Occurrence, per year**	**Subsequent Release Rate, kg/s**
E1	10 kg/h internal release	Yes	Yes	1.09E-02	1.92E-06
E2	10 kg/h internal release	Yes	No	5.76E-04	2.41E-03
E3	10 kg/h internal release	No	Yes	1.11E-04	1.44E-03
E4	10 kg/h internal release	No	No	5.82E-06	2.41E-03
E5	100 kg/h internal release	Yes	Yes	3.65E-03	1.92E-05
E6	100 kg/h internal release	Yes	No	1.92E-04	2.41E-02
E7	100 kg/h internal release	No	Yes	3.69E-05	1.44E-02
E8	100 kg/h internal release	No	No	1.94E-06	2.41E-02
E9	500 kg/h internal release	Yes	Yes	3.65E-03	9.61E-05
E10	500 kg/h internal release	Yes	No	1.92E-04	1.21E-01
E11	500 kg/h internal release	No	Yes	3.69E-05	7.22E-02
E12	500 kg/h internal release	No	No	1.94E-06	1.21E-01
E13	1000 kg/h internal release	Yes	Yes	3.65E-03	1.92E-04
E14	1000 kg/h internal release	Yes	No	1.92E-04	2.41E-01
E15	1000 kg/h internal release	No	Yes	3.69E-05	1.44E-01
E16	1000 kg/h internal release	No	No	1.94E-06	2.41E-01

External Release			
Event ID	**Initial Event**	**Frequency of Occurrence, per year**	**Subsequent Release Rate, kg/s**
E17	Truck Accident – 1 drum with small leak	5.78E-06	1.73E-02
E18	Truck Accident – 1 drum with large leak	2.22E-06	1.23E-01
E19	Truck Accident – 1 drum (catastrophic failure)	8.90E-07	1 ton instantaneous
E20	Truck Accident – 3 drum with small leak	5.46E-09	5.19E-02
E21	Truck Accident – 3 drum with large leak	2.01E-09	3.69E-01
E22	Truck Accident – 3 drum (catastrophic failure)	8.40E-10	3 ton instantaneous
E23	Truck Accident – 6 drum with small leak	2.01E-13	1.04E-01
E24	Truck Accident – 6 drum with large leak	5.04E-07	7.38E-01
E25	Truck Accident – 6 drum (catastrophic failure)	3.10E-14	6 ton instantaneous
E26	Truck Accident – spontaneous drum failure with small leak	2.20E-07	1.73E-02
E27	Truck Accident – spontaneous drum failure with large leak	1.71E-07	1.23E-01
E28	Truck Accident – spontaneous catastrophic rupture of 1drr	1.63E-08	1 ton instantaneous
E29	Earthquake –valve and pipping of 8mm equivalent hole size	1.42E-07	1.23E-01
E30	Earthquake –piping from valve to manifold	1.70E-06	6.80E-01
E31	Earthquake –piping from manifold to change over panel / regulator	7.36E-07	6.80E-01
E32	Earthquake –piping from vacuum regulator to chlorinator	4.25E-07	6.80E-01
E33	Earthquake –valve failure of 1 drum	6.00E-06	1.23E-01
E34	Earthquake – 1 drum instantaneous failure	1.00E-06	1 ton instantaneous
E35	Aircraft accident	9.27E-10	7 ton instantaneous

Annex B: Consequence Results from HA2018

Table B1 LD Contours of Various Release Scenarios

Event ID.	Wind speed & stability	3% fatality		50% fatality		95% fatality	
		Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)
E1	B2	<1	<1	<1	<1	<1	<1
E1	C4	<1	<1	<1	<1	<1	<1
E1	D3	<1	<1	<1	<1	<1	<1
E1	D3	<1	<1	<1	<1	<1	<1
E1	E3	<1	<1	<1	<1	<1	<1
E1	F1.5	<1	<1	<1	<1	<1	<1
E2	B2	8	<1	3	<1	2	<1
E2	C4	8	<1	3	<1	2	<1
E2	D3	13	1.6	5	<1	2	<1
E2	D3	13	1.6	5	<1	2	<1
E2	E3	19	1.6	8	<1	4	<1
E2	F1.5	42	4	17	2	6	<1
E3	B2	6	<1	3	<1	<1	<1
E3	C4	6	<1	3	<1	<1	<1
E3	D3	10	1.7	4	<1	2	<1
E3	D3	10	1.7	4	<1	2	<1
E3	E3	14	1.8	6	<1	3	<1
E3	F1.5	31	2.2	13	1.5	4	<1
E4	B2	8	<1	3	<1	2	<1
E4	C4	8	<1	3	<1	2	<1
E4	D3	13	1.6	5	<1	2	<1
E4	D3	13	1.6	5	<1	2	<1

Event ID.	Wind speed & stability	3% fatality		50% fatality		95% fatality	
		Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)
E4	E3	19	1.6	8	<1	4	<1
E4	F1.5	42	4	17	2	6	<1
E5	B2	<1	<1	<1	<1	<1	<1
E5	C4	<1	<1	<1	<1	<1	<1
E5	D3	<1	<1	<1	<1	<1	<1
E5	D3	<1	<1	<1	<1	<1	<1
E5	E3	<1	<1	<1	<1	<1	<1
E5	F1.5	<1	<1	<1	<1	<1	<1
E6	B2	24	8	10	3.4	5	<1
E6	C4	24	5	10	2.2	4	<1
E6	D3	41	5	17	2.4	8	<1
E6	D3	41	5	17	2.4	8	<1
E6	E3	60	6	25	2.3	12	1.7
E6	F1.5	125	20	43	10	16	4
E7	B2	18	6	7	<1	3	<1
E7	C4	18	4	7	<1	3	<1
E7	D3	30	4	12	2	6	<1
E7	D3	30	4	12	2	6	<1
E7	E3	44	4	18	1.8	9	1.1
E7	F1.5	98	12	34	6	12.79	3.2
E8	B2	24	8	10	3.4	5	<1
E8	C4	24	5	10	2.2	4	<1

Event ID.	Wind speed & stability	3% fatality		50% fatality		95% fatality	
		Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)
E8	D3	41	5	17	2.4	8	<1
E8	D3	41	5	17	2.4	8	<1
E8	E3	60	6	25	2.3	12	1.7
E8	F1.5	125	20	43	10	16	4
E9	B2	<1	<1	<1	<1	<1	<1
E9	C4	<1	<1	<1	<1	<1	<1
E9	D3	<1	<1	<1	<1	<1	<1
E9	D3	<1	<1	<1	<1	<1	<1
E9	E3	<1	<1	<1	<1	<1	<1
E9	F1.5	<1	<1	<1	<1	<1	<1
E10	B2	55	17	23	8	11	2.3
E10	C4	54	13	22	4.4	10	2.2
E10	D3	95	12	41	5	21	4
E10	D3	95	12	41	5	21	4
E10	E3	144	16	61	8	27	5.6
E10	F1.5	237	44	81	26	31	12
E11	B2	40	13	17	5.6	8	<1
E11	C4	40	8	16	3.8	7	<1
E11	D3	69	9	29	3.6	15	2
E11	D3	69	9	29	3.6	15	2
E11	E3	101	10	43	4	21	4
E11	F1.5	186	32	63	14	24	8.2

Event ID.	Wind speed & stability	3% fatality		50% fatality		95% fatality	
		Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)
E12	B2	55	17	23	8	11	2.3
E12	C4	54	13	22	4.4	10	2.2
E12	D3	95	12	41	5	21	4
E12	D3	95	12	41	5	21	4
E12	E3	144	16	61	8	27	5.6
E12	F1.5	237	44	81	26	31	12
E13	B2	<1	<1	<1	<1	<1	<1
E13	C4	<1	<1	<1	<1	<1	<1
E13	D3	<1	<1	<1	<1	<1	<1
E13	D3	<1	<1	<1	<1	<1	<1
E13	E3	<1	<1	<1	<1	<1	<1
E13	F1.5	<1	<1	<1	<1	<1	<1
E14	B2	79	24	34	11.8	17	5.2
E14	C4	76	15	31	5.4	14	2.8
E14	D3	142	20	62	8	32	8
E14	D3	142	20	62	8	32	8
E14	E3	218	20	89	12	35	8.4
E14	F1.5	313	80	107	32	41	18
E15	B2	57	17	24	8	12	34
E15	C4	56	10	23	5.2	10	2.2
E15	D3	99	10	43	5	22	4
E15	D3	99	10	43	5	22	4

Event ID.	Wind speed & stability	3% fatality		50% fatality		95% fatality	
		Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)
E15	E3	151	14	64	9	28	5.2
E15	F1.5	245	42	84	22	32	13.2
E16	B2	79	24	34	11.8	17	5.2
E16	C4	76	15	31	5.4	14	2.8
E16	D3	142	20	62	8	32	8
E16	D3	142	20	62	8	32	8
E16	E3	218	20	89	12	35	8.4
E16	F1.5	313	80	107	32	41	18
E17	B2	19	6	9	2	4	<1
E17	C4	18	4	8	0	4	<1
E17	D3	34	4	15	2	8	<1
E17	D3	34	4	15	2	8	<1
E17	E3	49	5	21	2	11	1
E17	F1.5	104	14	36	6	14	3
E18	B2	56	16	25	7	14	4
E18	C4	53	12	23	5	11	2
E18	D3	94	10	42	5	22	5
E18	D3	94	10	42	5	22	5
E18	E3	138	10	59	8	26	5
E18	F1.5	229	48	78	23	31	12
E19	B2	648	262	414	250	225	180
E19	C4	862	220	503	220	242	140

Event ID.	Wind speed & stability	3% fatality		50% fatality		95% fatality	
		Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)
E19	D3	1127	360	482	230	238	160
E19	D3	1127	360	482	230	238	160
E19	E3	1242	360	527	240	257	160
E19	F1.5	1101	460	503	300	278	220
E20	B2	35	10	16	5	8	0
E20	C4	33	6	14	3	7	0
E20	D3	60	8	27	4	14	2
E20	D3	60	8	27	4	14	2
E20	E3	86	9	37	4	18	4
E20	F1.5	162	27	55	13	22	7
E21	B2	100	30	47	13	26	10
E21	C4	95	20	42	8	22	4
E21	D3	176	20	77	12	35	10
E21	D3	176	20	77	12	35	10
E21	E3	269	20	103	20	40	11
E21	F1.5	357	80	122	42	48	24
E22	B2	940	480	583	360	330	260
E22	C4	1270	320	695	320	344	220
E22	D3	1525	520	668	340	340	230
E22	D3	1525	520	668	340	340	230
E22	E3	1685	520	728	350	367	250
E22	F1.5	1506	680	709	450	408	340

Event ID.	Wind speed & stability	3% fatality		50% fatality		95% fatality	
		Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)
E23	B2	51	15	23	6	13	3
E23	C4	48	10	21	4	10	2
E23	D3	86	10	39	5	20	4
E23	D3	86	10	39	5	20	4
E23	E3	125	10	53	6	24	5
E23	F1.5	214	40	73	20	29	10
E24	B2	148	43	70	20	38	18
E24	C4	140	28	61	12	32	6
E24	D3	267	32	113	24	46	15
E24	D3	267	32	113	24	46	15
E24	E3	395	50	136	30	52	16
E24	F1.5	471	130	162	62	65	35
E25	B2	1527	700	722	500	420	350
E25	C4	1600	520	848	400	426	280
E25	D3	1848	700	818	440	425	300
E25	D3	1848	700	818	440	425	300
E25	E3	2036	700	891	450	457	320
E25	F1.5	1839	860	886	600	520	440
E26	B2	19	6	9	2	4	<1
E26	C4	18	4	8	0	4	<1
E26	D3	34	4	15	2	8	<1
E26	D3	34	4	15	2	8	<1

Event ID.	Wind speed & stability	3% fatality		50% fatality		95% fatality	
		Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)
E26	E3	49	5	21	2	11	1
E26	F1.5	104	14	36	6	14	3
E27	B2	56	16	25	7	14	4
E27	C4	53	12	23	5	11	2
E27	D3	94	10	42	5	22	5
E27	D3	94	10	42	5	22	5
E27	E3	138	10	59	8	26	5
E27	F1.5	229	48	78	23	31	12
E28	B2	648	262	414	250	225	180
E28	C4	862	220	503	220	242	140
E28	D3	1127	360	482	230	238	160
E28	D3	1127	360	482	230	238	160
E28	E3	1242	360	527	240	257	160
E28	F1.5	1101	460	503	300	278	220
E29	B2	56	16	25	7	14	4
E29	C4	53	12	23	5	11	2
E29	D3	94	10	42	5	22	5
E29	D3	94	10	42	5	22	5
E29	E3	138	10	59	8	26	5
E29	F1.5	229	48	78	23	31	12
E30	B2	314	400	113	114	46	37
E30	C4	149	110	70	36	34	14

Event ID.	Wind speed & stability	3% fatality		50% fatality		95% fatality	
		Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)
E30	D3	156	150	73	52	36	22
E30	D3	156	150	73	52	36	22
E30	E3	174	164	81	56	40	24
E30	F1.5	591	800	212	240	86	80
E31	B2	314	400	113	114	46	37
E31	C4	149	110	70	36	34	14
E31	D3	156	150	73	52	36	22
E31	D3	156	150	73	52	36	22
E31	E3	174	164	81	56	40	24
E31	F1.5	591	800	212	240	86	80
E32	B2	314	400	113	114	46	37
E32	C4	149	110	70	36	34	14
E32	D3	156	150	73	52	36	22
E32	D3	156	150	73	52	36	22
E32	E3	174	164	81	56	40	24
E32	F1.5	591	800	212	240	86	80
E33	B2	56	16	25	7	14	4
E33	C4	53	12	23	5	11	2
E33	D3	94	10	42	5	22	5
E33	D3	94	10	42	5	22	5
E33	E3	138	10	59	8	26	5
E33	F1.5	229	48	78	23	31	12

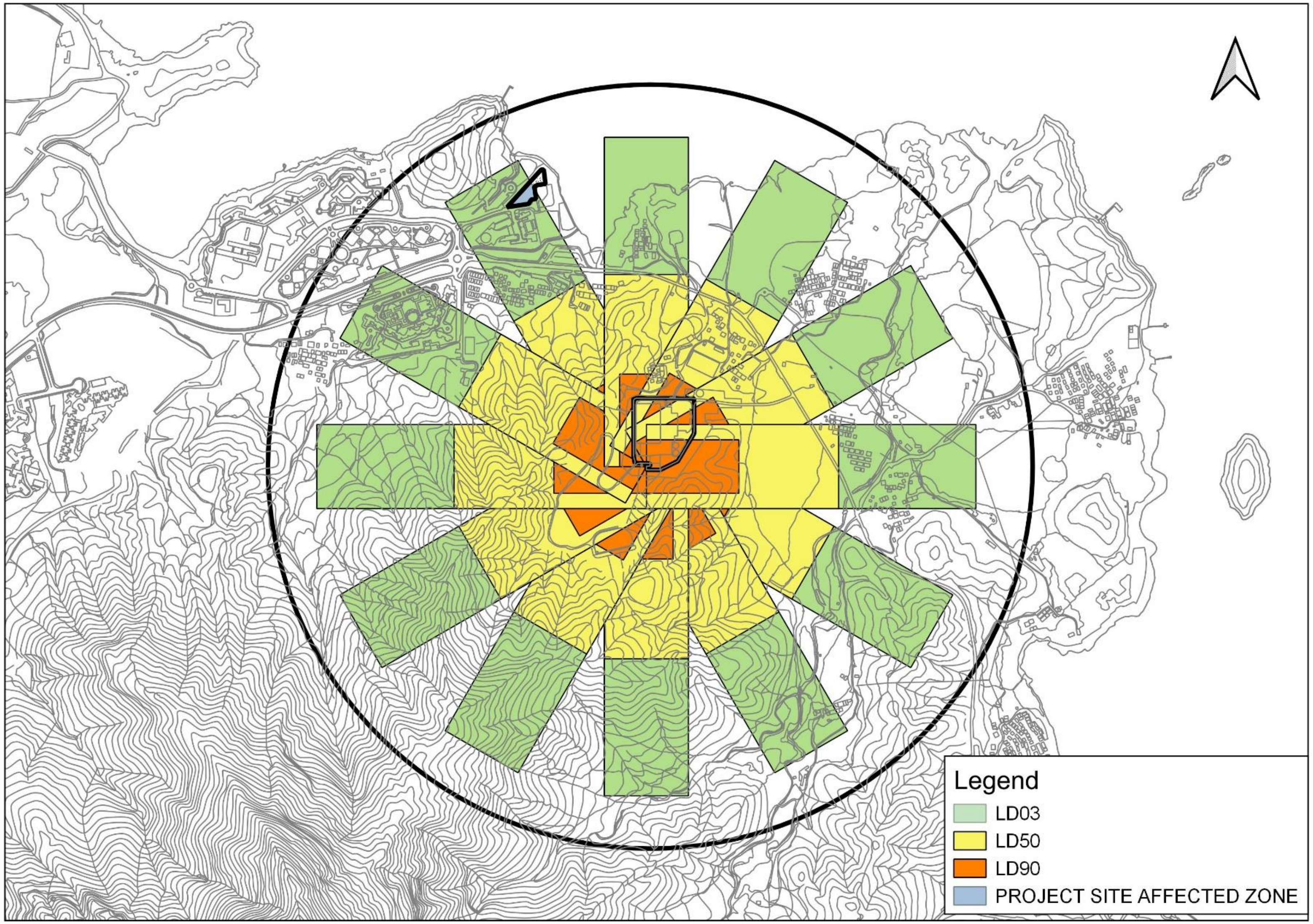
Event ID.	Wind speed & stability	3% fatality		50% fatality		95% fatality	
		Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)	Downwind (m)	Crosswind (m)
E34	B2	648	262	414	250	225	180
E34	C4	862	220	503	220	242	140
E34	D3	1127	360	482	230	238	160
E34	D3	1127	360	482	230	238	160
E34	E3	1242	360	527	240	257	160
E34	F1.5	1101	460	503	300	278	220
E35	B2	1620	1800	791	820	407	430
E35	C4	1325	1280	661	620	348	340
E35	D3	1464	1420	725	700	377	365
E35	D3	1464	1420	725	700	377	365
E35	E3	1602	1600	786	760	406	400
E35	F1.5	2162	2300	1046	1070	524	600

Note:

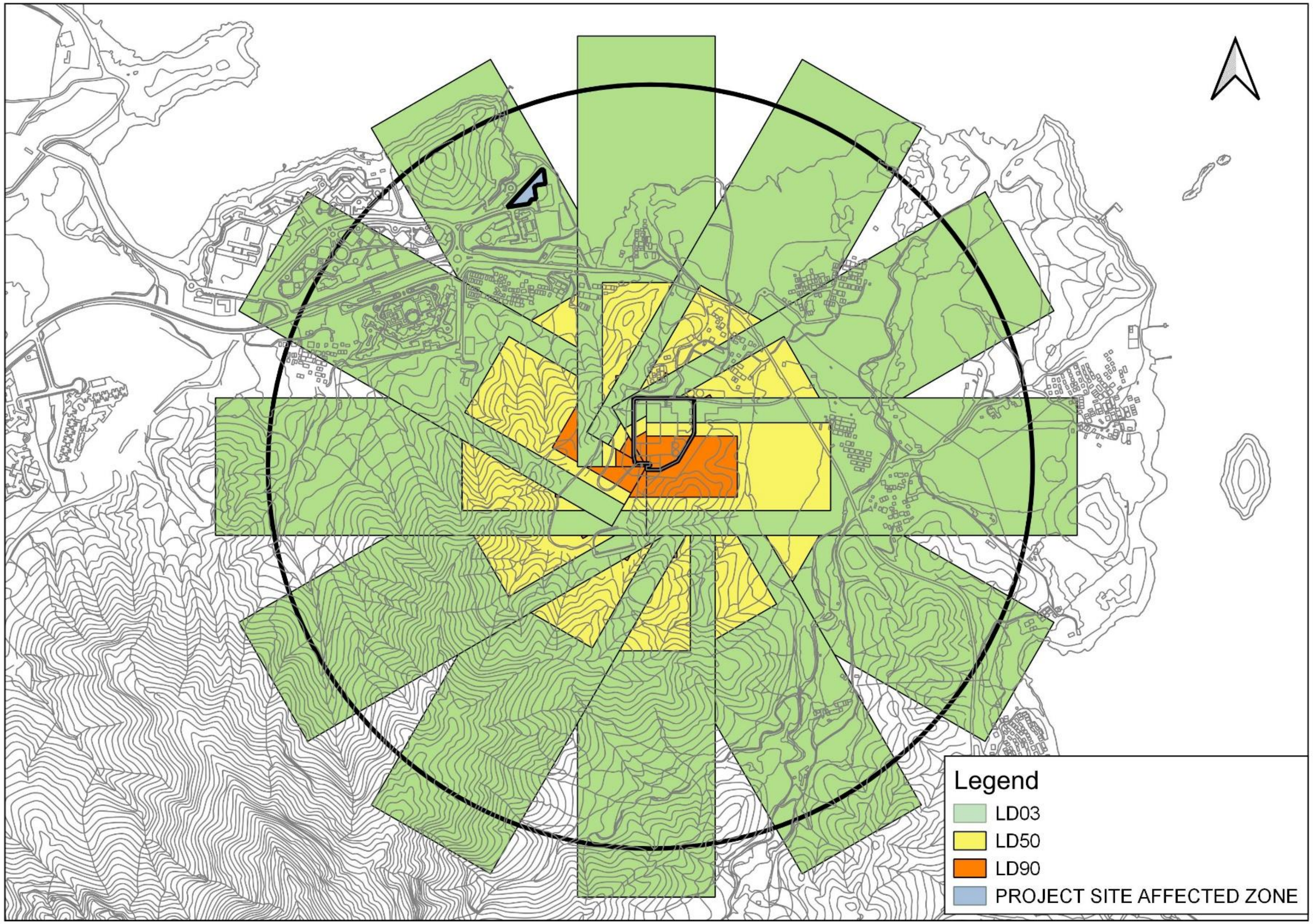
Cells highlighted in grey or purple were not considered since the contours have no offsite impact or the event frequencies are less than 9E-10 per year.

Annex C:
Illustration of LD Contours

LD Contour of 1 Tonne Instantaneous Release – Stability C4 (Event ID. E19, E28, E34)



LD Contour of 1 Tonne Instantaneous Release – Stability D3 (Event ID. E19, E28, E34)



Annex D:
Example of Risk Summation Calculation

Calculation of F-N curve of Construction Phase

For Event ID E19, only the consequences of LD03 in the wind direction from 135-164 degree are able to affect the Project Site.
According to **Section 3.1.1**, it is assumed that there will be 30 construction workers present during day time.
The event frequency of E19 is 8.90E-07 per year according to **Annex A**.
The calculation of the F-N pairs of E19 is shown below in form of table.

Time Period	Base Frequency (per year) (A)	Temporal Change (B)	Time Period % (C)	Frequency in the Time Period (per year) (D =A × C / ΣC)	Weather Probability (E)			Proportion of Project Site Covered by the Contour [(1)] (F)			Population in the time period (G = 30 × B)	Effective Fatality Probability [(2)] (H)
					B20	C40	D30	B20	C40	D30		
Night	8.90E-07	0%	0%	0.00E+00	0.009308	0.005771	0.020663	0	0.648	1	0	0.12
Jammed Peak	8.90E-07	100%	0.89%	1.58E-08	0.024827	0.014896	0.01468	0	0.648	1	30	0.12
Peak Hour	8.90E-07	100%	13.39%	2.38E-07	0.024827	0.014896	0.01468	0	0.648	1	30	0.12
Weekend day	8.90E-07	50%	9.53%	1.70E-07	0.024827	0.014896	0.01468	0	0.648	1	15	0.12
Working day	8.90E-07	100%	26.19%	4.66E-07	0.024827	0.014896	0.01468	0	0.648	1	30	0.12

Note

1. Portion of the Project Site covered is calculated according to the affect area divided by the total site area using information extracted by an in-house GIS software.
2. Geometrical mean of effective fatality probability of LD03 and LD50.

Time Period	No. of fatality (I = G × F × H)			Frequency of particular stability (J = D × E)		
	B20	C40	D30	B20	C40	D30
Night	0.000	0.000	0.000	0.00E+00	0.00E+00	0.00E+00
Jammed Peak	0.000	2.333	3.600	3.93E-10	2.36E-10	2.36E-10
Peak Hour	0.000	2.333	3.600	5.92E-09	3.55E-09	3.55E-09
Weekend day	0.000	1.167	1.800	4.21E-09	2.53E-09	2.53E-09
Working day	0.000	2.333	3.600	1.16E-08	6.94E-09	6.94E-09

By categorizing the no. of fatality and accumulating the corresponding frequencies, the F-N pairs can be calculated.

No. of Fatality	Frequency (per year)
>= 1	2.63E-08
>= 2	2.13E-08
>= 3	1.06E-08
>= 3.6	1.06E-08