Memorandum

To	Milford Opportunities Project
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From	Rob Bond, Harley Porter, Tim McMorran
Office	Christchurch
Date	26 June 2024
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Subject	MILFORD OPPORTUNITIES PROJECT NATURAL HAZARD ASSESSMENT PART B: BASIC RISK ASSESSMENT - Updated risk assessment – Supplementary Memo Report

1 Foreword

At the request of MOP representatives, WSP has been instructed to provide further information relating to the previously submitted risk assessment for tsunami hazards in Milford Sound Piopiotahi to support the MOP business case submission.

MOP has requested that the risk assessment outcomes are presented in a format more suited to the MOP objectives for Milford Sound Piopiotahi than the previous WSP report (ref), which follows the GNS Guidelines for Natural Hazard Risk Analysis on Public Conservation Lands and Waters (2022).

Through discussion with the MOP representatives, it has been made clear that this supplementary information request is to be an addendum to the REV D report (WSP, 2024) previously published and that the supplementary information presented in this document has not been externally peer reviewed.

It should be noted that, whilst the risk assessment outcomes are consistent with the REV D report, the approach to the risk calculation and presentation of data outcomes is different. This is explained in detail below. The outcomes of this supplementary assessment do not supersede or replace the conclusions and risk values presented in the REV D report.

2 Introduction

For tsunami hazards the REV D risk assessment report (WSP, 2024) considered risk for the Milford Sound Piopiotahi area (including Freshwater Basin, Deepwater Basin, Cleddau Delta, Visitor Hub, Milford Sound Lodge, and Little Tahiti).

Three landslide-induced tsunami events, MLE, MCE and AF8 (most likely event, maximum credible event, and alpine fault event) were considered and estimates of fatality risk for visitors and workers in Milford Sound Piopiotahi were then calculated.

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Return periods and wave heights for the events were based on published work (Dykstra, 2012; Taig & McSaveney, 2015; AF8, 2024).

The three landslide-induced tsunami events considered as part of this report are as follows:

- The most likely event (MLE) considers a ~1:1000-year annual exceedance probability (AEP) landslide-induced tsunami wave with a 6.3 m runup at Cleddau Delta.
- The maximum credible event (MCE) considers a ~1:17,000-year AEP landslide-induced tsunami wave with a 45.9 m runup at Cleddau Delta.
- The alpine fault event (AF8) considers a Magnitude 8 earthquake (AF8) triggering a landslide-induced tsunami in Milford Sound Piopiotahi. This is estimated to have a ~1:150-year AEP landslide-induced tsunami wave with a 5 m runup at Cleddau Delta.

Visitor risk was expressed in individual risk per day (IRPD) for one-off visits to Milford Sound Piopiotahi while worker risk was expressed in Annual Individual Fatality Risk (AIFR) for individuals working in Milford Sound Piopiotahi.

To estimate risk, the probability of each tsunami wave reaching exposed individuals in Milford Sound Piopiotahi $P_{(T:H)}$ and the chance of fatality (Vulnerability $V_{(D:T)}$) was calculated using professional judgment informed by topographical information and methods presented in international studies.

For detailed methodology of this risk assessment, the reader is referred to the previous WSP report (WSP, 2024).

The results of the risk assessment were reported in the REV D report (WSP, 2024) in direct accordance with the published GNS Guidelines for Natural hazard Risk Analysis on Public Conservation Lands and Waters (2022) and this work was externally peer reviewed by the Department of Conservation (DoC) and their nominated peer review panel (AECOM).

Due to various complexities and uncertainties in the calculation of risk for individual sites/locations as well as the likely skew of higher risk towards coastal areas the results of the risk assessment were, at the direction of the peer review panel, amalgamated as one area of risk, i.e. the risk values calculated for individual sites were combined. This enabled an assessment of the average risk presented for the Milford Sound Piopiotahi areas.

In addition, the previous REV D report (WSP, 2024) presented risk calculations for Societal risk in terms of annual probable lives lost (APLL). This supplementary assessment does not consider Societal risk at individual sites/nodes.

3 Supplementary Assessment (June 2024)

As noted above MOP has now requested that WSP consider the risk values for individual sites/nodes in Milford Sound Piopiotahi as opposed to the amalgamated approach presented in the REV D report.

This addendum therefore presents the risk estimates for visitor and worker risk at each site/node identified in Milford Sound Piopiotahi to the three landslide-induced tsunami events, MLE, MCE and AF8.

However, it should be noted that there is significant uncertainty and limitations in determining risk parameter values for individual site locations due to the complexity of landslide-induced tsunami events, tsunami wave dissipation, and likelihood of fatality given a certain wave height, topographic considerations, and population at risk distribution.

The results presented in this report should be considered preliminary and must therefore be accompanied with the limitations and assumptions presented in Section 6 below.

Calculated risk values are compared to existing risk tolerability criteria developed by the Department of Conservation (Table 1) (DoC). DoC has developed visitor-type classes which include the typical activities undertaken and the relative risk tolerance levels for each class. To determine risk tolerability for the average visitor and worker, the DoC risk tolerability criteria for lower risk tolerance sites have been used. This assumes the predominant visitor class in Milford Sound Piopiotahi are *Short Stop Traveller (SST) and Day Visitor (DV).*

Table 1:The DOC risk tolerability criteria for sites used in this study.

Risk level	IRDP (visitor) (lower risk tolerance site)	AIFR (worker)
High/Extreme	>1.00E-05	>3.00E-04
Substantial	>1.00E-06	>1.00E-04
Moderate higher	1.00E-07 to 1.00E-06	>1.00E-05
Moderate lower	n/a	>1.00E-06
Low	<1.00E-07	<1.00E-06

4 Updated Results

4.1 Most likely event (MLE) and maximum credible event (MCE)

Table 2 below presents the results of the tsunami risk assessment for visitors (IRPD) and workers (AIFR) exposed to the most likely and maximum credible landslide-induced tsunami events in Milford Sound Piopiotahi.

Risk values are a product of the hazard probability $P_{(H)}$, hazard impact probability $P_{(T:H)}$, vulnerability $V_{(D:T)}$, and the annual exposure for visitors and workers $P_{(S:T}$ (Appendix - Table 4 and Table 5).

Exposure times adopted in this assessment are provided in Table 7 (Appendix) and are based on current visitor and worker activity. As we have classified visitor and worker exposure in bands in this report, $P_{(S:T)}$ is given as a range with a lower and upper value. IRPD and AIFR estimates include both the 'most likely' and 'maximum credible' event to provide an overall estimate of risk.

Visitor risk for tsunami in Milford Sound Piopiotahi is estimated as

- 'Moderate' to 'substantial' for Visitor Hub.
- 'Moderate' for Cleddau Delta, Deepwater Basin, Freshwater Basin, and Milford Sound Lodge.
- 'Low' for Little Tahiti.

For workers, risk is estimated as

- 'Substantial' to 'high/extreme' for Cleddau Delta and Deepwater Basin.
- 'Substantial' for Freshwater Basin and Visitor Hub.
- 'Moderate' to 'substantial' for Milford Sound Lodge.
- 'Moderate' for Little Tahiti

Table 2: Visitor (IRPD) and worker (AIFR) for both the most likely (SM17 - Taig & McSaveney (2015)) and maximum credible (SM15 – Taig & McSaveney (2015)) landslide-induced tsunami event in Milford Sound Piopiotahi. Rev D assessment in bold.

Site / Node	IRPD – visitor		AIFR – worker	
	Lower	Upper	Lower	Upper
Rev D report Milford Sound Piopiotahi sites -combined	**7.5E-07**	**1.5E-06**	**1.3E-04**	**2.6E-04**
Cleddau Delta	1.1E-07	3.2E-07	2.2E-04	4.5E-04
Deepwater Basin	1.1E-07	3.2E-07	2.2E-04	4.5E-04
Freshwater Basin	4.3E-07	7.5E-07	1.4E-04	2.2E-04
Visitor Hub	8.5E-07	1.7E-06	1.5E-04	3.0E-04
Milford Sound Lodge	4.4E-07	8.8E-07	7.7E-05	1.5E-04
Little Tahiti	0.0E+00	0.0E+00	2.3E-05	4.5E-05

Note -Little Tahiti IRPD values represent zero use or presence at the site.

4.2 Alpine Fault Event (AF8)

Table 3 below presents the results of the tsunami risk assessment for visitors (IRPD) and workers (AIFR) exposed to the AF8 event in Milford Sound Piopiotahi.

Risk values are a product of the hazard probability $P_{(H)}$, hazard impact probability $P_{(T:H)}$, vulnerability $V_{(D:T)}$, and the annual exposure for visitors and workers $P_{(S:T}$ (Appendix Table 6).

Visitor risk for tsunami in Milford Sound Piopiotahi is estimated as

- 'High/Extreme' for Visitor Hub and Milford Sound Lodge.
- 'Substantial' to 'High/Extreme' for Freshwater Basin.
- 'Substantial' for Cleddau Delta and Deepwater Basin.
- 'Low' for Little Tahiti.

For workers, risk is estimated as

- 'High/Extreme' for all sites.

Table 3: Visitor (IRPD) and worker (AIFR) for both the most likely and maximum credible landslide-induced tsunami event in Milford Sound Piopiotahi using the cumulative return of the Alpine Fault. Rev D assessment in bold.

Site	IRPD – visitor		AIFR - worker	
	Lower	Upper	Lower	Upper
REV D report Milford Sound Piopiotahi sites – combined	**1.2E-05**	**2.4E-05**	**2.1E-03**	**4.2E-03**
Cleddau Delta	1.5E-06	4.6E-06	3.2E-03	6.3E-03
Deepwater Basin	1.5E-06	4.6E-06	3.2E-03	6.3E-03
Freshwater Basin	6.1E-06	1.1E-05	2.0E-03	3.1E-03
Visitor Hub	1.4E-05	2.7E-05	2.4E-03	4.7E-03
Milford Sound Lodge	1.1E-05	2.2E-05	1.9E-03	3.8E-03
Little Tahiti	0.0E+00	0.0E+00	7.6E-04	1.5E-03

Note -Little Tahiti IRPD values represent zero use or presence at the site.

5 Summary

At the request of MOP WSP has presented the results of the completed risk assessment for individual sites / nodes as opposed to the amalgamated results presented in the REV D report (WSP, 2024).

The revised presentation of the results highlights the high and extreme risks presented to workers and visitors to the coastal areas of Milford Sound Piopiotahi and the likely lower risk for sites located inland and upstream of the Cleddau Delta.

However, the assessment of individual sites has been made using various assumptions, limitations and engineering judgment, has not been externally peer reviewed and does not align with the GNS risk analysis framework.

In addition, the assessment of Societal risk for both current and future populations (visitors/workers) of the areas has not been undertaken as part of this supplementary report.

6 Limitations and assumptions

- The probabilities of the hazard occurring $P_{(H)}$ are based on Dykstra (2012), Taig & McSaveney (2015) and AF8 (2024). The reader is referred to these studies for uncertainties and limitations of earthquake and tsunami events.
- Probability of hazard reaching the site $P_{(T:H)}$, exposure $P_{(S:T)}$, and vulnerability $V_{(D:T)}$ were estimated for each site. These estimations are based on technical understanding of the type of hazard, comparison with similar assessment undertaken elsewhere around the world and discussion with the external peer review expert panel members. It should be noted however that;
    - There is large uncertainty in estimating $P_{(T:H)}$ due to little available knowledge of what tsunami dissipation would occur overland and upriver in Milford Sound Piopiotahi.
    - Without detailed tsunami modelling – including detailed analysis of existing infrastructure and structures any estimates for $P_{(T:H)}$ in Milford Sound Piopiotahi are preliminary and have a high level of uncertainty.
    - Separating Milford Sound Piopiotahi into individual sites results in more overall risk parameter estimates as there are now six sites to consider rather than one.
- Exposure times between individuals may vary considerably.
- Future population distribution and use of the site by various visitor groups is uncertain.
- Vulnerability and stability of buildings is uncertain.

7 References

AF8. (2024). *AF8 Hazard Scenario*. Retrieved from https://af8.org.nz/what-is-af8

Dykstra, J. (2012). The Post-LGM Evolution of Milford Sound, Fiordland, New Zealand: Timing of Ice Retreat, the Role of Mass Wasting & Implications for Hazards.

Taig, T., & McSaveney. (2015). *Milford Sound risk from landslide-generated tsunami.* GNS Science.

WSP. (2024). *Milford Opportunities Project Natural Hazard Assessment Part B: Basic Risk Assessment. Dated 11 June 2024.*

Appendix – Risk Input Variable Tables

Table 4: Landslide-induced tsunami probability $P_{(H)}$ and vulnerability $V_{(D:T)}$ for the most likely event in Milford Sound Piopiotahi. Most likely event probability is based on SM17 presented in Dykstra (2012).

Site	Most likely event			
	Runup at Cleddau Delta (m)	$P_{(H)}$	$P_{(T:H)}$	$V_{(D:T)}$
Milford Sound Piopiotahi sites	6.3	8.8E-04	0.7	0.8
Cleddau Delta	6.3	8.8E-04	1	1.0
Deepwater Basin	6.3	8.8E-04	1	1.0
Freshwater Basin	6.3	8.8E-04	1	1.0
Visitor Hub	6.3	8.8E-04	0.8	0.8
Milford Sound Lodge	6.3	8.8E-04	0.6	0.5
Little Tahiti	6.3	8.8E-04	0.4	0.2

Table 5: Landslide-induced tsunami probability $P_{(H)}$ and vulnerability $V_{(D:T)}$ for the maximum credible event in Milford Sound Piopiotahi. Maximum credible event probability is based on SM15 presented in Dykstra (2012).

Site	Maximum credible event			
	Runup at Cleddau Delta (m)	$P_{(H)}$	$P_{(T:H)}$	$V_{(D:T)}$
Milford Sound Piopiotahi sites	45.9	5.9E-05	0.9	1
Cleddau Delta	45.9	5.9E-05	1	1
Deepwater Basin	45.9	5.9E-05	1	1
Freshwater Basin	45.9	5.9E-05	1	1
Visitor Hub	45.9	5.9E-05	1	1
Milford Sound Lodge	45.9	5.9E-05	1	1
Little Tahiti	45.9	5.9E-05	0.7	0.6

Table 6: Landslide-induced tsunami probability $P_{(H)}$ and vulnerability $V_{(D:T)}$ for the Alpine fault-induced events in Milford Sound Piopiotahi. Runup is based on SM7, SM10, and SM20 presented in Dykstra (2012).

Site	Most likely				Maximum credible			
	Runup at Cleddau Delta (m)	$P_{(H)}$	$P_{(T:H)}$	$V_{(D:T)}$	Runup at Cleddau Delta (m)	$P_{(H)}$	$P_{(T:H)}$	$V_{(D:T)}$
Milford Sound Piopiotahi sites	5	6.7E-03	0.6	0.7	45.9	6.7E-03	0.9	1
Cleddau Delta	5	6.7E-03	1	1	45.9	6.7E-03	1	1
Deepwater Basin	5	6.7E-03	1	1	45.9	6.7E-03	1	1
Freshwater Basin	5	6.7E-03	1	1	45.9	6.7E-03	1	1

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Visitor Hub	5	6.7E-03	0.7	0.7	45.9	6.7E-03	1	1
Milford Sound Lodge	5	6.7E-03	0.5	0.4	45.9	6.7E-03	1	1
Little Tahiti	5	6.7E-03	0.3	0.2	45.9	6.7E-03	0.7	0.6

Table 7: Estimated visitor and worker exposure in Milford Sound Piopiotahi.

Site	Visitor Expsoure $P_{(S:T)}$		Worker Exposure $P_{(S:T)}$	
	Lower	Upper	Lower	Upper
Milford Sound Piopiotahi sites	0.001369863	0.002739726	0.237442922	0.474885845
Cleddau Delta	0.000114155	0.000342466	0.237442922	0.474885845
Deepwater Basin	0.000114155	0.000342466	0.237442922	0.474885845
Freshwater Basin	0.000456621	0.000799087	0.148401826	0.231506849
Visitor Hub	0.001369863	0.002739726	0.237442922	0.474885845
Milford Sound Lodge	0.001369863	0.002739726	0.237442922	0.474885845
Little Tahiti	0	0	0.237442922	0.474885845