BEFORE THE FAST-TRACK APPROVALS PANEL

In the matter of the Fast-Track Approvals Act 2024

And

In the Matter of applications by Oceana Gold (New Zealand) Limited for various resource consents relating to the Waihi North Project (Wharekirauponga Underground Mine)

And

In the matter of the submission on the above applications

by Coromandel Watchdog of Hauraki Inc

Brief of evidence of Denis Charles Tegg

Dated: 23 August 2025

Evidence of Denis Charles Tegg:

1. Introduction

1.1 My full name is Denis Charles Tegg.

1.2 I hold a Bachelor of Arts degree and a Bachelor of Laws degree from Otago University.

1.3 I practiced law in Thames for 45 years between 1974 and 2019, with a satellite office in Whangamata for a decade.

1.4 I was the elected representative for Thames Coromandel on the Waikato Regional Council between 2019 and 2022

1.5 Throughout my legal career I have taken a keen interest in proposals for development within the conservation estate on the Coromandel Peninsula, including scores of applications for exploration and mining consents.

1.6 In the late 1990's I was the architect of a Private Members Bill introduced to Parliament by Judith Tizard, MP which sought limitations on mining within the conservation estate north of Te Aroha. The Bill was referred to a Select Committee after significant public and iwi support, but it did not pass in its original form.

1.7 Its influence led to amendments in the Crown Minerals Act 1991 in 1997, which added protections under Schedule 4, prohibiting above ground mining on conservation land and coastal areas north of the Kopu-Hikuai Road (State Highway 25).

1.8 These Schedule 4 provisions relating to the Coromandel Peninsula have remained intact in New Zealand law.

1.9 In 1996 I was instructing solicitor in *Coromandel Peninsula Watchdog Inc v Hauraki District Council & Coeur Gold New Zealand Ltd* — High Court (Hamilton Registry), Hammond J, M301/96, 19 December 1996 This was a judicial review challenging the Council's decision under the Building Act 1991 to grant building consents for remedial works to the Golden Cross/Waitekauri tailings dam following stability concerns and a major landslip under the dam. The Watchdog group argued the Council misapplied the Building Act and failed to properly consider safety risks. The High Court reviewed whether the Council acted lawfully in issuing consents for buttressing and dam strengthening, balancing environmental and seismic safety issues with statutory compliance.

1.10 I have read the conditions for resource consents proposed by Thames Coromandel District Council, Hauraki District Council and Waikato Regional Council

1.11 I do not present myself as an expert in the seismic safety of tailings dams.

1.12 However, I have developed skills in reviewing and analysing technical documents, and in identifying inconsistencies or gaps between the conclusions or assumptions of witnesses and the findings available in peer-reviewed literature.

1.13 It is within this context that I present the following evidence for the Panel's consideration.

1.14 I have also generally reviewed the first iteration of consent conditions. I have not reviewed, but seek an opportunity to review, the latest iteration of consent conditions, and related documents. Unfortunately these arrived too late in preparation of my evidence.

2. Scope of Evidence

2.1 My evidence is presented in 4 Sections:

A. Re-evaluation of Te Puninga and Kerepehi Faults Seismic Risk to Waihi Tailings Storage Facilities

B. Re-evaluation of Hikurangi Subduction Zone Seismic Risk to Waihi Tailings Storage Facilities

C. Lessons from Waitekauri Tailings Dam Landslide 1996

D. Environmental and Socio-Economic Impacts Downstream of Paeroa of a Tailings Dam Breach

3. Section A

Re-Evaluation of Te Puninga and Kerepehi Faults - Seismic Risk to Waihi Tailings Storage Facilities

3.1 Executive Summary

3.1.1 This section provides an evaluation of Oceana Gold (OG) documents concerning seismic and liquefaction risk for the proposed Waihi goldmining tailings dam expansion. OG's assessment fundamentally relies on seismic hazard data (GNS 2017) that has been significantly superseded by more recent, un-cited research. The studies by Villamor et al. (2024) and Dempsey et al. (2020) introduce critical updates regarding the Te Puninga Fault's independence and increased magnitude, the potential underestimation of the Kerepehi Fault's slip rate, the credible risk of larger multi-fault ruptures (up to Mw 7.45), and pronounced basin amplification effects within the Hauraki Rift.

3.1.2 These new insights collectively suggest higher ground motions and an increased liquefaction potential for both the tailings and surrounding infrastructure than implicitly or explicitly considered by OG. Consequently, OG's conclusions regarding the robustness of risk assessment, the "highly unlikely" probability of dam breach, and the dismissal of distant Hikurangi mega-quakes as non-credible risks require rigorous re-evaluation (See Section B). This section recommends the mandatory incorporation of these recent studies, a comprehensive re-assessment of ground motion parameters and of InSAR satellite data on land movement, and a detailed re-evaluation of liquefaction potential under updated seismic loading conditions to ensure the highest standards of seismic design safety are met.

3.2 Introduction

3.2.1 This section presents a critique of Oceana Gold (New Zealand) Limited's (OGNZL) consent documents concerning the seismic design safety of their large-scale goldmining tailings dams near Waihi, New Zealand. The evaluation specifically targets the assessment of earthquake and liquefaction risks within sections 3.2, 3.3, 4.2.6, 5.0, and 7.1.2 of the submitted documentation. A central tenet of this review involves the integration and rigorous evaluation of OGNZL's claims against recent, pertinent research from Dempsey et al. (2020) and Villamor et al. (2024). These pivotal studies do not appear to have been cited in OGNZL's documents and postdate the technical assessments referenced therein.

3.3 Review of Seismic Hazard Assessment (Oceana Gold Sections 3.2 & 3.3)

3.3.1 Oceana Gold's documents [1] articulate the seismic hazard for the Waihi site, primarily drawing upon a GNS Science assessment from 2017. This assessment identifies the Kerepehi Fault System, situated 21 km from the site, as the Controlling Maximum Earthquake (CME). The largest rupture scenario for this system is described as a Mw 7.3 event, spanning approximately 81 km with an estimated 3.6 meters of normal (dip-slip) fault displacement, occurring with a recurrence interval of about 10,000 years.[1] The Hikurangi Subduction Zone, located over 200 km distant from

Waihi, is acknowledged as capable of generating Mw 9 earthquakes. However, its ground motions are considered to be attenuated over this distance and are therefore dismissed as not a significant risk to the TSFs.[1] OGNZL also notes that the 2022 National Seismic Hazard Model (NSHM) indicates higher numbers than the 2017 study but asserts that these changes "do not make a material difference" to the assessed performance of the Tailings Storage Facilities (TSFs).[1]

3.4 Critique based on Villamor et al. (2024) Findings

3.4.1 Villamor et al. (2024) provides a critical and more recent update to the understanding of seismic sources in the Waihi region, particularly concerning the Te Puninga Fault.

3.4.2 The study definitively establishes the Te Puninga Fault (TPF) as an independent seismic source, a significant reclassification from its previous consideration as merely a segment of the nearby Kerepehi Fault (KF).[1] This re-evaluation is based on new, detailed mapping and field data. The research further provides a new net slip rate for the TPF of 0.25 mm/yr, a value slightly higher than previously assumed.[1] The estimated characteristic earthquake magnitude for the TPF is Mw 6.9 ± 0.35 [1], with a derived recurrence interval for TPF ruptures ranging from 3000 to 11,500 years.[1] New Peak Ground Acceleration (PGA) and Modified Mercalli Intensity (MMI) estimates for the TPF are also presented, indicating values slightly larger than prior studies.[1] For a Mw 6.9 event, specific towns in the region are projected to experience significant shaking: Morrinsville MMI 9.7 ± 1.02, Te Aroha MMI 8.9 ± 1.04, Hamilton MMI 7.9 ± 1.03, and Tauranga MMI 6.6 ± 1.04.[1]

3.4.3 The recognition of the Te Puninga Fault as an independent, active source with a substantial magnitude (Mw 6.9) and a higher slip rate than previously thought implies that the cumulative seismic hazard from proximal faults to Waihi (Kerepehi and Te Puninga) is potentially greater than what was assessed in the 2017 GNS study. The 2017 assessment might have treated the TPF as part of the KF, thereby potentially underestimating its individual contribution or its complex interaction with the Kerepehi Fault. This suggests that the seismic input parameters currently utilized for the dam design may be non-conservative. The proximity of both the Kerepehi Fault (21 km) and the newly characterised Te Puninga Fault means that the Waihi TSFs are exposed to potentially higher and more intricate ground motions than are currently accounted for in the consent documents.

3.4.4 Furthermore, Villamor et al. (2024) states that "Comparisons of geomorphic expression between the two faults suggest that the slip rate currently assigned to the Kerepehi Fault could be underestimated".[1] If the Kerepehi Fault's slip rate is indeed underestimated, it directly implies a higher frequency of large earthquakes or potentially larger magnitudes than are currently modeled by OGNZL. This directly impacts the probabilistic seismic hazard analysis (PSHA) for the Waihi site, potentially increasing the ground motion values for various return periods and calling into question the robustness of OGNZL's conclusions about seismic risk, as a fundamental input parameter for the controlling fault is potentially non-conservative.

3.4.5 Villamor et al. (2024) also explicitly discusses the potential for multi-fault ruptures, a scenario where the Te Puninga Fault could co-rupture with other regional faults such as the Kerepehi, Mangatangi, Aka Aka, and Pokeno faults. Such events are estimated to generate earthquakes of Mw 7.25–7.45, with recurrence intervals ranging from 5656 to 10398 years.[1] While OGNZL's 2017 GNS study mentions a Mw 7.3 for a full Kerepehi rupture [1], the explicit identification and detailed discussion of a broader multi-fault system with potentially larger magnitudes (Mw 7.25-7.45) in Villamor et al. (2024) represents a more severe scenario. The 2016 Kaikoura earthquake (Mw 7.8) serves as a recent, compelling example of complex, multi-fault ruptures [1], underscoring the critical importance of considering such scenarios in seismic design. OGNZL's assertion that NSHM 2022 updates "do not make a material difference" [1] must be rigorously re-examined in light of these specific multi-fault rupture magnitudes and their associated recurrence intervals. The design basis earthquake (Safety Evaluation Earthquake, SEE) for the Waihi TSFs should explicitly account for these larger, more complex multi-fault rupture scenarios, which could generate ground motions exceeding those derived from a single-fault Mw 7.3 Kerepehi event.

3.5 Critique based on Dempsey et al. (2020) Findings

3.5.1 Dempsey et al. (2020) provides physics-based ground motion simulations that highlight crucial regional effects not typically captured by conventional empirical models.

3.5.2 The study demonstrates that the Hauraki Rift and Hamilton/Waikato basins significantly amplify long-period (>1s) shaking by a factor of two to three.[1] This amplification is observed at various locations; for instance, Hamilton experiences two to three times higher pseudo-spectral acceleration (pSA) at 2 seconds than Huntly [1], and Ngātea shows pSA at 2 seconds averaging 0.5g compared to 0.25g at Matamata.[1] For Waihi specifically, a Mw 7.3 Kerepehi Fault rupture with a southern hypocentre is simulated to result in MMI 6.9 [6.3, 7.6], PGA 0.22g [0.15, 0.31g], and PGV 19.1 cm/s [12.3, 29.7 cm/s].[1]

3.5.3 OGNZL's seismic hazard assessment [1] provides PGA values (e.g., 0.23g for Mw 7.3 CME) for rock conditions and generally mentions amplification through soil profiles and embankments. However, it does not explicitly detail the potential for significant basin amplification of long-period ground motions as identified by Dempsey et al. (2020). The Waihi site is situated within the broader Hauraki Rift region, which is characterised by deep sedimentary basins. Long-period shaking is particularly damaging to large, flexible structures such as tailings dams. If the TSFs are founded on or adjacent to such basin structures, the actual ground motions experienced could be significantly higher, especially at longer periods, than implied by a simple PGA value or standard site amplification factors. Therefore, the seismic design of the TSFs needs to explicitly consider the amplified long-period ground motions due to basin effects, which may not be adequately captured by the 2017 GNS study or standard NSHM models if they do not fully resolve these shallow basin structures.

3.5.4 OGNZL's documents state that the Hikurangi Subduction Zone (Mw 9, >200 km distant) is attenuated and "not a credible risk".[1] (see Section B on the Hikurangi Subduction Zone) However, Dempsey et al. (2020) discusses the use of Mw 9.0 Cascadia megathrust earthquake simulations as input for modeling the structural response of buildings in Seattle.[1] While Dempsey's study does not directly model Hikurangi for Waihi, this discussion highlights that distant mega-quakes are considered relevant for structural analysis, especially concerning their long-period shaking content. While ground motions from a distant Mw 9 Hikurangi event would indeed be attenuated in amplitude, their long-period content could still be significant, particularly if amplified by the Hauraki Rift basin. Large-scale structures like tailings dams are inherently sensitive to long-period shaking. Dismissing this risk as "not credible" without a detailed assessment of long-period spectral accelerations and their potential amplification by local basin effects, even from distant sources, is not aligned with best practice for critical infrastructure. The argument of simple "attenuation" may be overly simplistic, neglecting the unique characteristics of mega-quakes and basin responses. A comprehensive assessment should therefore include scenario-based ground motion simulations for a Hikurangi megathrust event, specifically evaluating long-period shaking and potential basin amplification at the Waihi site.

3.6 Assessment of Robustness of Oceana Gold's Conclusions

3.6.1 Given the compelling findings from Villamor et al. (2024) and Dempsey et al. (2020), Oceana Gold's seismic hazard conclusions, which are based on a 2017 GNS study, do not appear fully robust. The emergence of the Te Puninga Fault as an independent, significant seismic source, the potential underestimation of the Kerepehi Fault's slip rate, and the explicit identification of larger multi-fault rupture scenarios (up to Mw 7.45) collectively introduce higher seismic demands than previously acknowledged. Furthermore, the significant basin amplification effects identified by Dempsey et al. (2020) imply that the ground motions experienced at the Waihi site, particularly at long periods, could be substantially higher than the PGA values derived from a 2017 study. The assertion that NSHM 2022 updates "do not make a material difference" [1] is questionable without a detailed re-evaluation against these specific new data points.

3.6.2 Table 1: Comparative Seismic Hazard Parameters for Waihi Region

Source/Study	Controlling Fault(s)	Magnitude (Mw)	Recurrence Interval (years)	PGA at Waihi (g)	Key Characteristic/Implication
Oceana Gold (GNS 2017)	Kerepehi Fault (CME)	7.3	10,000	0.23 (for SEE)	Primary design basis; assumes Hikurangi attenuated.
Villamor et al. (2024)	Te Puninga Fault (Independent)	6.9 ± 0.35	3,000-11,500	Slightly larger than prior	New independent source, higher slip rate than thought.
Villamor et al. (2024)	Kerepehi Fault	Underestimated slip rate	-	Potentially higher	Suggests KF hazard may be higher than currently assigned.
Villamor et al. (2024)	Multi-fault (Kerepehi-Te Puninga system)	7.25-7.45	5,656-10,398	Potentially higher	Credible larger, more complex rupture scenarios.

Dempsey et al. (2020)	Kerepehi Fault	7.3	-	0.22 (mean)	Physics-based simulation, highlights basin amplification.
Dempsey et al. (2020)	Hauraki Rift Basin	-	-	Factor of 2-3 amplification (long-period)	Significant amplification of long-period shaking.
Hikurangi Subduction Zone	9.0	-	-	Attenuated (OG) / Potentially significant long-period (Critique)	OG dismisses; critique suggests re-evaluation for long-period effects.

3.7 Assessment of Tailings Liquefaction Risk (Oceana Gold Section 4.2.6)

3.7.1 Oceana Gold's documents [1] characterise the tailings profile within the impoundments, noting that the material generally comprises cohesive low plasticity sandy silt and clayey silt, with occasional thin lenses of cohesionless (non-plastic) silt/sand material.[1] The fine-grained nature of these tailings is stated to result in a low permeability profile, with values estimated to reduce to less than 1E-8 m/s with consolidation.[1] Vane shear strengths are reported to be generally greater than 30 kPa around the impoundment perimeter, increasing to over 90 kPa at 17 meters depth, indicating a firm-stiff cohesive soil.[1] The pore water within the tailings is described as being in a sub-hydrostatic state. Critically, OGNZL states that while the tailings are saturated or partially saturated, "they can liquefy or cyclically soften in an earthquake where the shaking is equal or greater than that expected every 150 years on average".[1] However, a key design claim is that the embankments themselves are explicitly stated to be "NOT liquefiable and are designed to hold back a full profile of liquefied tailings".[1]

3.8 Detailed Critique using Dempsey et al. (2020) Data

3.8.1 Dempsey et al. (2020) provides specific ground motion intensity measures (IMs) that are highly relevant to liquefaction triggering, particularly within the Hauraki Depression, the broader geological context where the Waihi TSFs are located.

3.8.2 For a Mw 7.3 Kerepehi Fault rupture, Dempsey et al. (2020) simulates PGA values of 0.4–0.5g throughout the Hauraki Depression.[1] This is explicitly noted as being "larger than that associated with damage to stop-banks during 2010–11 Canterbury earthquake sequence (>0.2g)".[1] Furthermore, Cumulative Absolute Velocity (CAV) values are shown to exceed 2.0 g.s for rivers protected by stop-banks in the Hauraki Depression, and 1.0 g.s for parts of the Waikato River.[1] Numerical modeling cited in Dempsey et al. (2020) indicates that CAV values exceeding 2.0 g.s can lead to "settlement up to 0.6 m for very thick (~10 m liquefiable layers") .[1]

> 3.8.3 **Specifically for Waihi Dempsey et al. (2020) reports a simulated PGA of 0.22g [0.15, 0.31g] and CAV of 1.35 g.s [1.21, 1.49 g.s] for a Mw 7.3 Kerepehi Fault event.**[1]

3.8.4 OGNZL states that the tailings can liquefy with shaking "equal or greater than that expected every 150 years on average".[1] However, Dempsey et al. (2020) provides ground motions for a Mw 7.3 Kerepehi Fault event, which has a recurrence interval of approximately 10,000 years [1]. Even for this rarer event, Dempsey predicts a PGA of

0.22g and CAV of 1.35 g.s at Waihi.[1] More critically, in the broader Hauraki Depression, Dempsey's study shows PGA values of 0.4-0.5g and CAV values exceeding 2.0 g.s.[1] While Waihi's specific location close to the Hauraki Depression might experience slightly lower values than the peak regional values, the proximity to the Kerepehi Fault (21 km) and the potential for basin amplification [1] suggest that the actual seismic demand on the tailings and foundation could be significantly higher than the 150-year threshold mentioned by OGNZL for liquefaction initiation. The question therefore arises whether the "150 years on average" threshold is sufficiently conservative given the actual seismic environment and the potential for more severe, albeit less frequent, ground motions. The current liquefaction assessment may not fully capture the potential for widespread liquefaction within the tailings and underlying foundation soils under the updated, more severe seismic loading scenarios derived from Dempsey et al. (2020) and Villamor et al. (2024).

3.8.5 OGNZL's tailings are described as sandy silt/clayey silt with occasional silt/sand lenses.[1] This description aligns with the "sandy, silty deposits" susceptible to liquefaction mentioned by Dempsey et al. (2020), which also highlights the softening of "soft peat deposits and organic silts" leading to "settlement and slumping of stop-banks due to the reduced bearing capacity of the local soils, and lateral spreading induced cracking and extension".[1] While OGNZL states that the embankments themselves are non-liquefiable and designed to contain liquefied tailings [1], the broader implications of widespread liquefaction in the *foundation soils* beneath the dam or in the surrounding Hauraki Plains (including critical infrastructure like stop-banks protecting Paeroa) are not explicitly detailed in OGNZL's liquefaction section. Significant settlement, slumping, or lateral spreading of foundation soils could compromise the dam's integrity or lead to cascading failures of critical infrastructure (e.g., roads, bridges, flood defenses) even if the dam's embankment itself remains intact. Therefore, the liquefaction risk assessment needs to extend beyond just the tailings body to a detailed evaluation of the liquefaction potential and associated ground deformations (settlement, lateral spreading) of the natural foundation soils beneath the dam and critical downstream infrastructure, considering the elevated ground motions and CAV values from Dempsey et al. (2020).

3.9 Evaluation of Adequacy of Dam's Design to Contain Liquefied Tailings

OGNZL states that the embankments are "NOT liquefiable and are designed to hold back a full profile of liquefied tailings".[1] This is a crucial design philosophy for tailings dams. However, the robustness of this design claim needs to be re-evaluated against the updated seismic parameters. If the actual seismic loads (PGA, CAV, long-period shaking) are higher than the original design basis, or if the extent and severity of tailings liquefaction (e.g., flow liquefaction versus cyclic mobility) are underestimated, the ability of the non-liquefiable embankment to contain the liquefied mass could be compromised. This is particularly relevant if the foundation soils themselves undergo significant deformation, which could impact the embankment's stability and containment capacity.

3.10 Critique of General Tailings Dam Failure Discussion (Oceana Gold Section 5.0)

3.10.1 Oceana Gold's discussion [1] on tailings dam failures globally, in comparison to the Waihi TSFs, emphasises that the Waihi operation utilises the downstream construction method (earth and rockfill) rather than the higher-risk upstream method (where dams are constructed of tailings themselves), which has been prevalent in many global failures.[1] OGNZL asserts that their embankments "will not liquefy and have good resistance to earthquake loadings" [1] and that other potential failure modes are managed through "proper design, construction, operation, monitoring and surveillance".[1] The company also highlights that its parent corporation has a policy to avoid constructing new upstream TSFs.

3.11 Commentary on Best Practice and Robust Conclusions

3.11.1 OGNZL's commitment to the downstream construction method, which leverages readily available mine overburden [1], is indeed aligned with best practice for enhancing the stability and reducing the liquefaction risk of the embankment structure itself. This represents a significant advantage over upstream construction methods that have been associated with a greater number of failures globally.

3.11.2 However, the claim of "good resistance to earthquake loadings" [1] and that the embankments "will not liquefy" [1] is a strong assertion that requires re-validation. Its robustness hinges entirely on the accuracy and comprehensiveness of the seismic hazard inputs. As detailed in this section, the seismic hazard assessment presented by OGNZL (based on GNS 2017) potentially underestimates ground motions due to several factors. These include the independent nature and updated parameters of the Te Puninga Fault (Villamor et al., 2024), the potential underestimation of the Kerepehi Fault slip rate (Villamor et al., 2024), the credibility of larger multi-fault rupture scenarios (Mw 7.25-7.45) (Villamor et al., 2024), and the significant basin amplification effects (Dempsey et al., 2020) that can increase long-period shaking. If the actual seismic demand (PGA, MMI, CAV, long-period spectral accelerations) from these updated sources and effects is higher than the original design basis, then the "good resistance" and "non-liquefiable" claims for the embankment need to be rigorously re-validated through updated stability and deformation analyses. A design considered robust against a Mw 7.3 Kerepehi event (from the 2017 GNS study) might not be sufficiently robust against a Mw 7.45 multi-fault rupture with the added complexities of basin amplification effects. The quantitative assessment needs to be re-anchored to the most current and comprehensive seismic hazard data.

3.11.3 Furthermore, while OGNZL's discussion focuses on the embankment's non-liquefiable nature, a holistic risk assessment for "failure of tailings storage facilities" [1] should also explicitly acknowledge the potential for ground deformation (liquefaction-induced settlement, lateral spreading) in the *underlying foundation soils* or *surrounding infrastructure* (e.g., stop-banks) under the updated seismic demands. Dempsey et al. (2020) highlights this risk in the Hauraki Depression [1], indicating that even if the dam itself does not "fail" in a catastrophic sense, severe damage to surrounding infrastructure due to ground deformation could lead to significant environmental and social consequences.

3.12 Review of Tailings Technology Options (Oceana Gold Section 7.1.2)

3.12.1 Oceana Gold's documents [1] include a discussion on "Thickened Tailings" technology. The document correctly identifies several advantages of thickened tailings compared to conventional slurry tailings, such as a smaller footprint, higher strength, reduced water usage, and lower water evaporation losses.[1] However, OGNZL concludes that thickened tailings are "not suited to areas of high rainfall where earthquakes are possible".[1] The reasons cited for this unsuitability include the necessity for separate water storage ponds (which could lead to a larger overall footprint), the potential for erosion during heavy rainfall events, and their susceptibility to liquefaction or strength loss, which would then require extensive underdrainage and higher perimeter embankments.[1] The high capital costs associated with this technology are also noted as a deterrent.

3.13 Critique of Suitability and Design Requirements for Thickened Tailings

3.13.1 OGNZL's assessment that thickened tailings are "not suited" for the Waihi environment, characterised by high rainfall and earthquake activity, is generally consistent with established geotechnical earthquake engineering principles. The challenges of managing water in high rainfall environments when using thickened tailings, combined with their inherent susceptibility to liquefaction under seismic loading, are well-recognised within the field.

3.13.2 The updated seismic hazard data from Dempsey et al. (2020) and Villamor et al. (2024) further reinforces OGNZL's conclusion regarding the unsuitability of thickened tailings at Waihi. OGNZL states that thickened tailings "can also be susceptible to liquefaction or strength loss, requiring underdrainage to reduce the risks of liquefaction and the perimeter embankment to be higher to contain any earthquake induced slumping of the tailings".[1] The updated seismic hazard data, which indicates potentially higher ground motions (PGA, MMI, CAV) and long-period shaking, as well as the credibility of larger multi-fault ruptures (Mw 7.25-7.45), would exacerbate the liquefaction potential of thickened tailings. These elevated seismic demands would make the design requirements for underdrainage and perimeter embankments even more stringent and potentially economically unfeasible or technically challenging to achieve the desired safety factors. Therefore, the new seismic data strengthens the argument against using thickened tailings at Waihi, underscoring the prudence of OGNZL's current approach with conventional slurry tailings and robust downstream embankments.

3.14 Commentary on Catastrophic Failure and Risk Conclusions

3.14.1 Oceana Gold's Dam Breach and Impact Classification Assessment [1] concludes that the proposed Storage 3 TSF has a "HIGH Potential Impact Classification (PIC)".[1] This classification is primarily driven by a "Rainy Day breach scenario" associated with a 1 in 1,000-year return period flood. This hypothetical scenario is projected to lead to "catastrophic" impacts on major infrastructure and the natural environment, and a "major" impact on residential dwellings and community recovery time, which is assessed in "years".[1] The scenario also estimates an incremental Population at Risk (PAR) of 200 and a Potential Loss of Life of 2.[1] Despite these severe consequences, OGNZL states: "The risk of a breach into Paeroa is extremely low as a 1 in 1,000 year flood is unlikely and a breach of the TSFs is highly unlikely".[1]

3.15 Evaluation of "Catastrophic" Failure and "Highly Unlikely" Breach

3.15.1 OGNZL's assessment of "catastrophic" consequences for a 1 in 1,000-year rainfall event breach is a stark and appropriate recognition of the severe impacts that such a failure would entail.[1] This level of consequence correctly drives the "High Potential Impact Classification" for the facility.

3.15.2 However, the assertion that "a breach of the TSFs is highly unlikely" and the risk is "extremely low" [1] requires critical re-evaluation. While a 1 in 1,000-year flood is indeed a rare hydrological event, the probability of a *seismically-induced breach* or a *combined seismic-hydrological event* triggering a breach is a separate and crucial consideration. OGNZL's "Sunny Day" breach scenario explicitly mentions "instability of the embankment triggered by strong earthquake shaking" as a potential failure mode.[1] The updated seismic hazard information from Villamor et al. (2024) and Dempsey et al. (2020) indicates a more active and potentially more severe seismic environment than OGNZL's 2017 GNS basis. Specifically, the independent Te Puninga Fault (Mw 6.9) and the potential underestimation of the Kerepehi Fault slip rate (Villamor et al., 2024), coupled with the credible multi-fault rupture scenarios (Mw 7.25-7.45) (Villamor et al., 2024), suggest a higher seismic demand. Furthermore, the significant basin amplification effects (Dempsey et al., 2020) could lead to higher ground motions (PGA, CAV) and an increased liquefaction potential for both the tailings and surrounding soils. If these updated seismic events, which are not "extremely low" probability over the dam's lifespan, can trigger liquefaction of the tailings (as acknowledged by OGNZL [1]) or lead to significant ground deformation of the foundation, the probability of a breach (even a partial one) might be higher than implied by the term "highly unlikely." A seismic event could also compromise the dam's ability to withstand subsequent hydrological loading, creating a complex failure pathway. Therefore, the probability assessment for dam breach needs to integrate the full spectrum of updated seismic hazard scenarios, including the potential for earthquake-induced liquefaction and ground deformation, and consider their potential to trigger or exacerbate breach mechanisms. The current "highly unlikely" conclusion may be overly optimistic given the updated understanding of seismic risk.

3.15.3 It is concerning that the evidence presented by Oceana Gold to the Fast Track Approval Panel lacks a comprehensive assessment of land movement rates and extent across its existing Waihi gold mining operation, including the open pit, waste dumps, and tailings dam. This constitutes a significant evidentiary gap, particularly given the readily available and highly accurate InSAR (Interferometric Synthetic Aperture Radar) satellite data. Providers like Satsense, (https://satsense.com/) routinely collect and process this information. Earth Sciences New Zealand (https://www.gns.cri.nz/) hold licences for New Zealand-specific data and may be an additional source.

InSAR technology offers millimetre-level precision in measuring vertical ground deformation, and to a lesser extent, horizontal movement, making it an indispensable tool for monitoring the stability of large-scale infrastructure. Mining companies and regulatory bodies globally routinely utilise InSAR data for critical assessments such as slope stability in open pits, settlement of waste rock dumps, and the integrity of tailings dam embankments. This case study from Wigan in the UK relating to mining operations illustrates the essential nature of this data in consent hearings. (https://satsense.com/case-studies/Monitoring-The-Impact-Of-Mining-Activities)

For the Panel to make a robust and informed decision regarding the consent application and the long-term safety of the expanded operations, this vital and routinely available land movement data is essential for understanding the dynamic geological and geotechnical performance of the Waihi site.

3.16 Conclusions and Recommendations

3.16.1 Oceana Gold's approach to tailings dam design and safety management at Waihi demonstrates a commitment to the use of downstream embankments, and an adherence to the New Zealand Dam Safety Guidelines (NZDSG). The identification of a "High Potential Impact Classification" for the Storage 3 TSF and the acknowledgment of "catastrophic" consequences for a breach event correctly reflect a responsible understanding of the potential severity.

3.16.2 However, a critical review reveals a significant concern: the underlying seismic hazard assessment, which forms the very foundation of the risk evaluation, is based on data that has been substantially updated by recent, un-cited research. This temporal gap introduces material concerns regarding the robustness and conservatism of the current risk conclusions.

3.17 Summary of Key Findings and Areas of Concern

3.17.1 **Underestimated Seismic Hazard:** The 2017 GNS study referenced by OGNZL appears to underestimate the regional seismic hazard. Villamor et al. (2024) establishes the Te Puninga Fault as an independent, active source (Mw 6.9 ± 0.35) and suggests that the Kerepehi Fault's slip rate may be underestimated. Both of these faults are geographically proximal to the Waihi site.

3.17.2 **Unaccounted Multi-Fault Ruptures:** OGNZL's assessment does not fully incorporate the credible multi-fault rupture scenarios (Mw 7.25-7.45) identified by Villamor et al. (2024). These scenarios could generate more severe ground motions than are currently considered in the design basis.

3.17.3 **Neglected Basin Amplification:** Dempsey et al. (2020) demonstrates significant (factor of 2-3) long-period shaking amplification within the Hauraki Rift due to deep basin effects. This critical phenomenon, which is highly relevant to the dynamic response of large structures like TSFs, does not appear to be explicitly integrated into OGNZL's current seismic design parameters.

3.17.4 **Re-evaluation of Hikurangi Risk:** The dismissal of the Mw 9 Hikurangi megathrust as "not a credible risk" solely due to distance is an oversimplification. Attenuated long-period motions from such events, potentially amplified by local basins, could still pose a significant and damaging hazard to large, sensitive structures. (see Section B)

3.17.5 **Liquefaction Risk Underestimated:** While OGNZL acknowledges the tailings' liquefaction potential (at shaking levels exceeding a 150-year Average Recurrence Interval) and states that the embankments themselves are non-liquefiable, the seismic demands derived from updated studies (e.g., Dempsey's PGA of 0.22g and CAV of 1.35 g.s at Waihi for a Mw 7.3 Kerepehi event, and even higher regional values) suggest more severe liquefaction triggering conditions. The potential for widespread liquefaction and associated ground deformation in the underlying foundation soils and surrounding critical infrastructure (e.g., flood stop-banks) under these updated loads requires a more explicit and detailed assessment.

3.17.6 **Questionable "Highly Unlikely" Breach Probability:** The conclusion that a dam breach is "highly unlikely" is questionable given the updated understanding of seismic triggers, including earthquake-induced liquefaction and ground deformation. These phenomena could initiate or exacerbate failure mechanisms, potentially in combination with hydrological events, thereby increasing the overall probability of a breach.

3.17.7 **Lack of Highly Accurate InSAR Land Movement data** This constitutes a significant evidentiary gap. This data is routinely utilised for critical assessments such as slope stability in open pits, settlement of waste rock dumps, and the integrity of tailings dam embankments.

3.18 Specific, Actionable Recommendations

3.18.1 To ensure the Waihi goldmining tailings dams meet the highest standards of seismic design safety and align with contemporary best practice, the following recommendations are put forth:

3.18.2 **Mandatory Incorporation of Recent Research:** OGNZL must formally incorporate and re-evaluate its seismic hazard and risk assessments based on the comprehensive findings of Dempsey et al. (2020) and Villamor et al. (2024). These publications provide the most current and regionally specific understanding of seismicity.

3.18.3 **Updated Seismic Hazard Assessment:**

Conduct a comprehensive re-assessment of ground motion parameters for the Waihi site. This assessment must explicitly account for:

- The independent Te Puninga Fault and its updated seismic parameters (Mw 6.9, slip rate, recurrence interval).
- The potential underestimation of the Kerepehi Fault's slip rate, as suggested by recent geomorphic comparisons.
- The credible multi-fault rupture scenarios (Mw 7.25-7.45) involving the Te Puninga and Kerepehi fault systems, and their associated ground motions.
- Detailed basin amplification effects for long-period ground motions, utilizing physics-based simulations as demonstrated by Dempsey et al. (2020), specifically considering the Waihi site's location within the Hauraki Rift.
- Re-evaluate the Hikurangi Subduction Zone mega-quake risk. This re-evaluation should focus on the potential for significant long-period ground motions and their amplification by local site conditions and basin effects, rather than solely relying on a distance-based attenuation argument.
- Obtain and present to the Panel InSAR (Interferometric Synthetic Aperture Radar) satellite data for the present and proposed future mining operation locations.

3.18.4 **Comprehensive Liquefaction Re-evaluation:**

- Perform a detailed re-evaluation of the liquefaction potential for the tailings within the impoundments under the full spectrum of updated seismic loading conditions (PGA, CAV, duration, spectral content). This assessment should consider the full range of potential ground motions derived from the re-assessed seismic hazard.
- Extend the liquefaction assessment to include the natural foundation soils directly beneath the dam and critical surrounding infrastructure (e.g., flood stop-banks, roads, bridges in Waihi and Paeroa townships). This expanded assessment should quantify potential ground deformations such as settlement and lateral spreading and thoroughly evaluate their impact on dam stability and potential downstream consequences.

3.18.5 **Integrated Risk Assessment:**

- Review existing dam design and operational procedures to ensure enhanced resilience against combined extreme events, such as a significant seismic event occurring immediately prior to or concurrently with a major rainfall event.
- Re-assess the probability of dam breach. This re-assessment must explicitly incorporate the latest InSAR satellite data and the potential for earthquake-induced failure mechanisms (e.g., liquefaction-induced instability, ground deformation) as direct triggers or exacerbating factors, rather than solely focusing on hydrological overtopping or assuming a "highly unlikely" breach probability without full consideration of seismic interactions.

3.18.6 **Transparency and Documentation:**

- Ensure all updated assessments, methodologies, and conclusions are clearly documented and made accessible for independent peer review. This practice will align with the rigorous standards set forth by the NZDSG and the Global Industry Standard on Tailings Management, promoting accountability and confidence in the safety measures.

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3. Ground motion simulation of hypothetical earthquakes in the upper North Island of New Zealand. *New Zealand Journal of Geology and Geophysics*, *64*(4), 570-588. DOI: 10.1080/00288306.2020.1842469

4. Section B

Re-evaluation of Hikurangi Subduction Zone Seismic Risk to Waihi Tailings Storage Facilities

4.1 Executive Summary

4.1.1 This section presents a critical re-evaluation of the seismic hazard posed by the Hikurangi Subduction Zone (HSZ) to the Waihi Tailings Storage Facilities (TSFs). While Oceana Gold's current Maximum Credible Earthquake (MCE) assessment for Waihi focuses on a closer, moderate event, the analysis herein indicates that this approach appears to underestimate the credible risk from distant Mw 9 Hikurangi mega-thrust earthquakes. Scientific evidence confirms the HSZ's capacity for such large events, and while peak ground motions attenuate over distance, damaging long-period ground motions persist and can be significantly amplified by local basin effects. Tailings Storage Facilities, being large, flexible earth structures, are inherently vulnerable to these long-period motions and the associated risk of liquefaction. A robust seismic hazard assessment, aligned with New Zealand and international best practices, necessitates a more comprehensive consideration of these complex seismic phenomena.

4.2 Introduction: Context and Objectives

4.2.1 Purpose of the Re-evaluation

4.2.2 This section provides a comprehensive re-assessment of the seismic hazard posed by the Hikurangi Subduction Zone to the Waihi Tailings Storage Facilities (TSFs). It critically examines the prevailing assumption that distant mega-thrust earthquakes from the HSZ pose a non-credible risk to the TSFs solely due to attenuation. The section also evaluates Oceana Gold's current seismic hazard assessment considering contemporary international and New Zealand best practices for dam safety.

4.2.3 Overview of the Hikurangi Subduction Zone (HSZ)

4.2.3.1 The Hikurangi Subduction Zone is recognised as potentially the largest source of earthquake and tsunami hazard in New Zealand.[1] This active plate boundary, located off the East Coast of the North Island, is where the Pacific tectonic plate subducts beneath the Australian tectonic plate.[1] A large team of national and international scientists are actively engaged in studying the HSZ to understand the frequency and magnitude of potential earthquake events.[1] For instance, GNS Science has developed an Mw 8.9 scenario that serves as a "serious and credible basis" for national response planning, acknowledging the zone's capacity for large, tsunamigenic events.[3] The Hikurangi margin exhibits diverse slip styles along its length, ranging from recurring great (Mw > 8.0) earthquakes in the southern Hikurangi to shallow slow slip events and aseismic creep in the central and northern sections.[2] Historical events, such as the Mw ~7.0 tsunami earthquakes in 1947 offshore Poverty Bay and Tokomaru Bay, further demonstrate the zone's potential for significant seismic activity.[4]

4.2.4 Introduction to Waihi TSFs and their Critical Importance

4.2.4.1 The Waihi Operation encompasses existing Tailings Storage Facilities, specifically Storage 1A and Storage 2, with a new Storage 3 facility also proposed.[5] These facilities are designed as earth/rock-fill water-retaining structures, serving a critical role in managing the fine-grained waste materials, known as tailings, discharged from the mining process.[6] The integrity of these structures is paramount, as their failure, particularly due to seismic activity, carries the potential for significant environmental pollution and poses severe safety risks to downstream communities.[7] Tailings can contain hazardous substances, including cyanide and potentially acid-forming materials, which, if released, would severely contaminate surrounding rivers, streams, and land (see Section D on these issues) .[6]

4.2.3 Query Context

4.2.3.1 The central concern of this re-evaluation stems from a challenge to the dismissal of distant Hikurangi mega-quakes as "non-credible risks" for the Waihi TSFs. The HSZ, despite being over 200 km distant from Waihi, is acknowledged as capable of generating Mw 9 earthquakes. The prevailing view is that ground motions from such events are sufficiently attenuated over this distance to be dismissed as insignificant risks to the TSFs. This section directly addresses this perspective by providing a comprehensive critique of the underlying assumptions.

4.3 Characteristics of Distant Megathrust Earthquake Ground Motions

4.3.1 Hikurangi Subduction Zone's Mw 9 Potential - Evidence and Scenarios for Great Earthquakes

4.3.1.1 The Hikurangi margin is a globally significant focus for subduction zone research, with extensive investigations advancing the understanding of its megathrust slip behavior.[2] Paleoseismic studies have revealed a history of recurring great earthquakes (Mw > 8.0), particularly in the southern Hikurangi region.[2] This geological evidence is supported by contemporary scientific assessments. GNS Science, New Zealand's leading earth science research institute, has developed an Mw 8.9 scenario as a "serious and credible basis" for national response planning, explicitly acknowledging the zone's potential for large, tsunamigenic events.[3] The ongoing subduction of the Pacific Plate beneath the North Island is a fundamental process that can cause such large earthquakes, akin to those observed in Japan or Indonesia.[1]

4.3.2 Tectonic Setting and Slip Behaviour

4.3.2.1 The HSZ accommodates the westward subduction of the Pacific Plate beneath the North Island of New Zealand.[2] This dynamic tectonic setting results in a spectrum of slip behaviours along the megathrust fault, ranging from large tsunami-genic earthquakes to slow slip events (SSEs) and aseismic creep.[2] The variability in slip behaviour is influenced by heterogeneous properties of the plate boundary zone, including factors such as sediment thickness, the compressional nature of the overriding plate, and the roughness of the incoming plate.[2] While SSEs are characterized by slow, unnoticeable ground movements over weeks to months, the underlying driving forces for these events are considered to be the same as those for large, damaging, tsunamigenic subduction zone earthquakes.[1] This indicates a fundamental connection between the more frequent SSEs and the potential for rare, but devastating, megathrust ruptures.

4.3.3 The "Credibility" of Mw 9 Events

4.3.3.1 The assertion that Mw 9 Hikurangi events are "non-credible risks" solely due to distance, as implied in Oceana Gold's assessment, requires careful examination. The scientific community, as evidenced by GNS Science's development of an Mw 8.9 scenario for response planning, considers such large events a "serious and credible basis" for hazard assessment.[3] Furthermore, peer-reviewed studies confirm the occurrence of recurring great (Mw > 8.0) earthquakes in the southern Hikurangi.[2] In seismic hazard assessment, "credible" refers to events that are physically possible and possess a non-negligible probability of occurrence within a relevant timeframe, even if they are infrequent. Given the geological evidence and the consensus among leading scientists regarding the HSZ's potential, an Mw 9 event, while rare, is scientifically plausible and must be considered in a robust hazard assessment for critical infrastructure. Dismissing such an event based *solely* on distance, without a comprehensive evaluation of the unique characteristics of large magnitude, long-period ground motions, represents an oversimplification of the seismic hazard.

4.4 Attenuation and Long-Period Ground Motion

4.4.1 Mechanisms of Ground Motion Attenuation over Long Distances

4.4.1.1 Ground motion generally diminishes in intensity with increasing distance from the seismic source. However, the characteristics of this attenuation for megathrust subduction earthquakes can vary significantly depending on the method used to measure distance, such as fault distance versus equivalent hypocentral distance.[11]

4.4.2 Magnitude Saturation for Peak Ground Motions vs. Persistence of Long-Period Energy

4.4.2.1 For very large earthquakes, specifically those with moment magnitudes (Mw) greater than 8.3, strong ground motion parameters like Peak Ground Acceleration (PGA) can exhibit "magnitude saturation" when fault distance is used in calculations.[11] This phenomenon means that PGA may not increase proportionally or significantly with increasing magnitude beyond Mw 8.3. For example, the mean intensity of maximum ground motions from the Mw 9.0 Tohoku earthquake was roughly similar to that from the Mw 8.3 Tokachi-oki earthquake when fault distance was considered.[11] This implies that a Mw 9 event might not necessarily produce significantly higher *peak* accelerations at a given distance compared to a slightly smaller, but still large, event.

4.4.2.2 Crucially, this magnitude saturation primarily applies to peak ground acceleration and does *not* extend to the duration or the long-period content of ground motions.[11] Long-period ground motions, characterised by periods of 1 second or longer, attenuate much more slowly with distance compared to higher-frequency motions.[13] The duration of strong shaking also increases substantially with earthquake magnitude; a megathrust earthquake can result in shaking lasting for several minutes, a duration far exceeding that of smaller events.[12]

4.4.3 Distinct Characteristics of Long-Period Ground Motions from Distant Subduction Events

4.4.3.1 Ground motions generated by distant, large-magnitude earthquakes are typically dominated by long-period components and exhibit significantly longer durations.[12] For instance, the 2011 Mw 9.0 Tohoku earthquake produced strong ground motions with durations exceeding 100 seconds and dominant periods ranging from 0.75 s to 1.25 s at distant sites.[15] This contrasts sharply with the predictions of most existing attenuation relationships and building codes, which often specify predominant periods shorter than 0.6 seconds.[16] The response spectrum for distant earthquakes shifts towards a longer period range, a critical characteristic that needs careful consideration in seismic hazard assessments.[16]

4.4.3.2 The simple assertion that "ground motions are considered to be attenuated over this distance" for the Hikurangi risk to Waihi, as stated in the Oceana Gold's report, is a fundamental misrepresentation of the behaviour of long-period ground motions from megathrust events. The critical point is that different frequency components of seismic waves attenuate at different rates. Long-period waves, which are particularly relevant for large and flexible structures, attenuate much more slowly and can persist for extended durations over vast distances. Therefore, a statement of general attenuation, without specifying which ground motion parameters (e.g., PGA versus long-period spectral acceleration, or duration) are being considered, and without accounting for the type of structure at risk (flexible TSFs), constitutes an oversimplification that can lead to a significant underestimation of the actual hazard. The phenomenon of magnitude saturation for peak accelerations further underscores that focusing solely on PGA for very large events can be misleading, as the area affected by strong shaking and the duration of shaking increase substantially with magnitude, even if the peak acceleration does not.

4.5 Ground Motion Prediction Equations (GMPEs) for Subduction Zones

4.5.1 Ground Motion Prediction Equations (GMPEs) are fundamental inputs for any seismic hazard assessment. These equations are developed to predict ground motion parameters (such as peak ground acceleration and spectral acceleration) based on earthquake magnitude, distance, and site conditions. Current GMPEs cover a wide range of magnitudes, up to Mw 9.1, and distances, often up to 300 km.[11] However, a significant challenge arises because conventional GMPEs and standard building codes frequently do not adequately capture the unique spectral shape and the dominance of long-period components characteristic of ground motions from distant subduction earthquakes.[16] This deficiency means that models designed for typical crustal earthquakes or closer events may not accurately represent the hazard from a distant megathrust.

4.5.2 New Zealand-specific GMPEs are under development, aiming to predict parameters like peak ground acceleration and pseudo spectral acceleration for periods ranging from 0.01 to 10 seconds, for moment magnitudes of 4.0 to 8.0, and rupture distances up to 400 km for shallow crustal earthquakes.[18] The challenge lies in adapting or applying these, or other international models, to accurately characterise ground motions from the Hikurangi Subduction Zone at distances relevant to Waihi.

4.5.3 If standard GMPEs, which may have informed Oceana Gold's assessment, do not accurately represent the long-period characteristics of distant subduction events, then any assessment relying exclusively on them would be inherently flawed for structures vulnerable to long-period motions. A robust assessment for Waihi must therefore either utilise or adapt GMPEs specifically validated for distant megathrust events and long-period motions or undertake site-specific ground motion simulations that explicitly account for these unique characteristics, rather than relying on generalised attenuation curves that might primarily reflect peak ground acceleration.

Table 1 provides a summary of key seismic parameters for the Hikurangi Subduction Zone and their relevance to the Waihi site.

4.6 Table 1: Key Seismic Parameters of Hikurangi Subduction Zone and Waihi Site

Parameter	Data	Relevance to Waihi TSFs
Source	Hikurangi Subduction Zone	Largest potential earthquake source for New Zealand.[1]
Potential Maximum Magnitude	Mw 8.9 - Mw 9.0+	Scientifically credible magnitude for response planning and recurring great earthquakes.[2]
Distance to Waihi	~200+ km	Distance over which ground motions attenuate, but long-period components persist.[13]
Dominant Period of Expected Ground Motion (at Waihi)	>1.0 second (Long-Period)	Critical for resonance with large, flexible structures like TSFs.[13]
Expected Duration of Strong Shaking (at Waihi)	Several minutes	Prolonged cyclic loading increases liquefaction potential and cumulative damage.[12]
Key Hazard Type	Megathrust earthquake, tsunamigenic potential	Capable of generating the world's largest earthquakes and tsunamis.[1]

Relevant Ground Motion Parameters for TSFs	Long-period spectral acceleration, Peak Ground Velocity (PGV), Ground Displacement, Duration	These parameters are more indicative of damage to TSFs than Peak Ground Acceleration (PGA) alone.[8]

4.7 Seismic Vulnerability of Tailings Storage Facilities

4.7.1 Susceptibility to Long-Period Ground Motions

4.7.1.1 Resonance Effects in Large, Flexible Structures

Large-scale structures, including high-rise buildings, long-span bridges, oil storage tanks, and critically, large, flexible earth structures such as tailings dams, are particularly susceptible to the effects of long-period ground motions.[13] This heightened vulnerability arises because the natural vibration periods of these massive structures often align with the dominant periods of seismic waves generated by distant mega-thrust earthquakes. When these periods match, a phenomenon known as resonance occurs, leading to significantly amplified structural responses and potentially increased damage.[13] The New Zealand Dam Safety Guidelines (NZSOLD) 2023 specifically highlight that tailings dams are "particularly susceptible to the effects of long-period ground motions".[20]

4.7.1.2 Impact on Structural Integrity and Deformation

Long-period ground motions can induce substantially larger peak ground velocities (PGV) and ground displacements compared to peak ground accelerations (PGA).[13] This translates to an increased response in the low-frequency region of the response spectrum, which for dams, can result in significant soil displacements, shear strains, and the potential for excessive deformation, cracking, and overall instability.[8]

While the general concept of long-period vulnerability applies to a wide range of large structures, tailings dams possess unique characteristics that amplify this risk. They are flexible earth structures.[6] The NZSOLD guidelines explicitly state that TSFs are "particularly susceptible to the effects of long-period ground motions".[20] This means that a generic Maximum Credible Earthquake (MCE) assessment, even if it considers some level of shaking, might fail to capture the specific dynamic response of a TSF to long-period, long-duration shaking. Such shaking can induce cumulative damage and large deformations that are not solely dependent on peak acceleration, making a tailored assessment essential.

4.8 Basin Amplification Effects at Distant Sites

4.8.1 Mechanisms of Seismic Wave Amplification in Sedimentary Basins

4.8.1.1 Sedimentary basins are geological formations that can significantly modify and amplify seismic ground motions, especially the long-period components.[13] This amplification occurs through several mechanisms, including the generation of basin-generated surface waves, complex interactions with the basin's geometry and stratigraphy, and waveguide effects that trap and channel seismic energy.[13] The presence of thick, soft upper clay layers within a basin can further enhance this amplification.[13] These effects can lead to "unusually high long-period ground motions over large regions," as famously demonstrated by the 1985 Michoacán earthquake, where Mexico City, located 400 km from the epicenter, experienced widespread destruction due to basin amplification of long-period motions.[13]

4.8.2 Potential for Localised Amplification at Waihi

4.8.2.1 While specific geological details of the Waihi site's basin characteristics are not extensively provided in the available information, there is the potential for ground motions to be "amplified by local basins." Mining areas frequently involve altered ground conditions, extensive unconsolidated fill, or underlying geological structures that can behave as sedimentary basins. These conditions could contribute to localised amplification of seismic waves.

4.8.2.2 The dismissal of distant Hikurangi events due to attenuation is further challenged by the potential for basin amplification. Even if ground motions attenuate over the 200+ km distance from the Hikurangi Subduction Zone, local geological conditions at Waihi—such as the presence of a sedimentary basin, engineered fill, or specific soil profiles—could re-amplify the attenuated long-period waves. This re-amplification effectively negates some of the distance-related attenuation for the critical long-period components. Consequently, the actual ground motion experienced by the TSF could be significantly higher than a simple distance-attenuation model might suggest, particularly for the frequencies most damaging to the dam structure. This compounding risk underscores the need for detailed site-specific investigations.

4.9 Liquefaction Hazard in Tailings Materials

4.9.1 Conditions and Mechanisms Leading to Liquefaction

4.9.1.1 Liquefaction is a critical seismic hazard characterised by a sudden loss of stiffness and strength in saturated granular soils, triggered by the cyclic loading effects of an earthquake.[19] This loss of strength results from a rapid build-up of porewater pressure within the soil, which, if it approaches the confining pressure, causes the effective stress to drop to near zero. When this occurs, the soil temporarily behaves as a heavy liquid.[19] Tailings materials, often fine-grained, angular, and deposited in a loose, water-rich slurry state, are inherently highly susceptible to liquefaction.[7] This susceptibility makes liquefaction a primary cause of tailings dam failures during seismic events.[8]

4.9.2 Consequences of Liquefaction-Induced Flow Slides and Instability

4.9.2.1 The most catastrophic consequence for TSFs subjected to seismic loading is flow liquefaction of the impounded tailings or the dam's foundation materials.[7] As previously discussed, distant mega-thrust earthquakes, with their characteristic long duration and dominant long-period content, are highly effective at generating the sustained cyclic loading necessary to trigger liquefaction in susceptible, loose, saturated tailings.[12] A liquefaction-induced failure typically results in a sudden and rapid loss of shear strength, leading to a flow slide where the liquefied tailings mass flows like a viscous fluid, causing catastrophic dam collapse and uncontrolled release of the impounded material.[19] Historical examples, such as the Mochikoshi dams in Japan during the 1978 Mw 7 earthquake, illustrate this danger, where one dam failed during the main shaking and another 24 hours later due to liquefaction.[19] The NZSOLD guidelines explicitly identify liquefaction and lateral spreading as "significant concerns for tailings dams" that require thorough assessment.[20]

4.9.2.2 The fact that liquefaction can manifest not only during the peak shaking but also *after* the main seismic event, as observed in the Mochikoshi dam failure where one dam failed 24 hours later, highlights a critical aspect of this hazard.[19] This delayed or cumulative failure mode underscores that the long duration of shaking from a distant mega-thrust event can be particularly problematic for liquefaction. Even if peak accelerations are not extreme due to distance-related attenuation, the *prolonged cyclic loading* at long periods can be highly effective in building up pore pressures and triggering liquefaction in susceptible tailings materials. This cumulative effect over an extended duration, rather than just instantaneous peak shaking, is a critical consideration often overlooked in simplified seismic assessments. While Oceana Gold states that consolidated tailings become "essentially soils with inherent shear strength" and that the risk of release is "almost inconceivable" after cessation of deposition [6], this statement, while potentially valid for static conditions, may not adequately address the dynamic liquefaction potential under prolonged seismic loading, especially if the consolidation is not uniform or complete throughout the tailings mass.

Table 3 provides a matrix summarising the various vulnerability mechanisms of tailings dams to seismic loading and their relevance to a distant Hikurangi Mw 9 event.

4.10 Table 3: Tailings Dam Vulnerability Matrix to Seismic Loading

Vulnerability Mechanism	Description/Cause	Potential Failure Mode(s)	Relevance to Hikurangi Mw 9 Event
Long-Period Resonance	Natural period of large TSFs aligns with long-period waves from distant mega-quakes.[8]	Excessive deformation, cracking, loss of freeboard, overtopping, internal erosion.	Highly relevant, as Mw 9 events generate significant long-period energy over long distances.[12]
Basin Amplification	Local geological structures (basins, soft soils) amplify specific frequency ranges of seismic waves.[13]	Increased ground motion intensity at site, leading to exacerbated direct impacts and liquefaction triggering.	Highly relevant, as Waihi may have local basin effects that amplify distant long-period waves.[13]
Liquefaction of Tailings	Loss of strength in saturated, loose tailings due to cyclic loading.[7]	Flow slide, complete dam collapse, massive release of tailings.	Highly relevant, primary failure mode for TSFs from distant, long-duration events.[19]
Liquefaction of Foundation Soils	Loss of strength in saturated, loose foundation soils beneath the dam.[19]	Foundation failure, lateral spreading, dam instability.	Relevant, if foundation materials are susceptible.[20]
Long-Duration Shaking Effects	Cumulative pore pressure build-up and degradation	Increased likelihood of liquefaction,	Highly relevant, Mw 9 events are characterized by

	of strength over extended shaking.[12]	progressive failure, delayed failure.	very long durations.[12]

4.11 Critique of Oceana Gold's Seismic Hazard Assessment for Waihi TSFs

4.11.1 Summary of Oceana Gold's Stated Seismic Design Basis

4.11.1.1 Oceana Gold states that the Waihi embankments have been designed to resist the effects of earthquake shaking from a Maximum Credible Earthquake (MCE).[6] This MCE has been "conservatively assessed to be a magnitude MW 7 earthquake at a distance of nine kilometres from the site".[6] Oceana Gold dismisses distant Hikurangi mega-quakes (Mw 9, over 200 km distant) as "non-credible risks" due to the assumption that their ground motions are sufficiently attenuated over such distances.

4.11.1.2 The concept of relying on a single MCE, particularly one focused on a near-field, moderate magnitude event (Mw 7 at 9 km), for a site like Waihi within a seismically active region like New Zealand, represents a simplification. A single MCE, especially when defined by its proximity and a magnitude that primarily drives peak ground acceleration, may not adequately capture the full spectrum of seismic hazards. This includes the unique characteristics of distant, large-magnitude, long-duration, long-period ground motions.[12] While a Mw 7 at 9 km would produce high peak ground accelerations, its frequency content and duration would differ significantly from a Mw 9 event occurring over 200 km away. A truly robust assessment for critical infrastructure like TSFs should consider multiple credible scenarios, including those that challenge the "closest large event" paradigm, especially given the known vulnerability of TSFs to long-period motions and liquefaction. The dismissal of Mw 9 Hikurangi events as "non-credible" based on this limited MCE suggests a potential gap in their hazard characterisation.

4.11.2 Re-evaluation of Distant Hikurangi Risk to Waihi

4.11.2.1 Based on the analysis presented in this section, a Mw 9 Hikurangi event, despite its distance of over 200 km from Waihi, is scientifically credible.[2] While peak ground accelerations from such an event would indeed be attenuated over this distance [11], the long-period components of ground motion would persist with significant energy.[12] These long-period motions are precisely the type of seismic input to which large, flexible structures like TSFs are particularly vulnerable.[8] Furthermore, local geological conditions at Waihi, such as the presence of sedimentary basins or engineered fill, could significantly amplify these long-period waves.[13] This amplification could lead to damaging ground motions characterised by high peak ground velocities, large ground displacements, and prolonged durations, which may not be adequately captured by an MCE defined as a Mw 7 earthquake at 9 km. The dismissal of a Mw 9 Hikurangi megathrust as "not a credible risk" solely due to distance is, therefore, an oversimplification. Scientific literature and historical precedents clearly demonstrate that distant mega-thrust events can cause significant damage to large, flexible structures due to long-period ground motions, even at distances of hundreds of kilometres. The 1985 Michoacán earthquake (Mw 8.0), which caused widespread destruction in Mexico City 400 km away due to basin amplification of long-period motions, serves as a compelling example.[13] This historical event underscores that distance alone is an insufficient criterion for dismissing a significant seismic hazard.

4.12 Adherence to Best Practices and Robustness

4.12.1 The New Zealand Dam Safety Guidelines (NZSOLD) 2023 provide detailed guidance for seismic hazard assessment for dams, including specific considerations for tailings dams.[20] For dams classified with a high Potential Impact Classification (PIC), which TSFs like Waihi are likely to be given the severe consequences of failure, the Safety Evaluation Earthquake (SEE) requires consideration of at least a 1 in 2,500 Annual Exceedance Probability (AEP) ground motion.[20] Crucially, NZSOLD explicitly states that "long-period ground motions can be a concern for tailings dams" because they are "particularly susceptible to the effects of long-period ground motions, which are often generated by distant large magnitude earthquakes".[20] The guidelines also emphasize the need for a "thorough assessment of liquefaction and lateral spreading potential".[20]

4.12.2 The Oceana Gold report's stated MCE (Mw 7 at 9 km) [6] and the dismissal of distant Mw 9 events appear to fall short of the comprehensive requirements outlined in NZSOLD 2023. This is particularly evident regarding the explicit consideration of long-period ground motions from distant large magnitude events and their specific impact on TSFs. Furthermore, the B.04-EGL-Tailings-Storage-Facility.pdf report explicitly states that details on seismic hazard assessment concerning the Hikurangi Subduction Zone and long-period ground motions are "unavailable".[5] This represents a significant gap in transparency and detailed information for a critical infrastructure project. While Oceana Gold mentions ongoing monitoring and independent peer review [5], the publicly available information suggests their MCE might not fully encompass the complex seismic hazard environment as understood by current best practices.

4.12.3 The NZSOLD 2023 guidelines are the authoritative national standard for dam safety in New Zealand.[20] Their explicit mention of long-period ground motions from *distant large magnitude earthquakes* as a specific concern for *tailings dams* directly contradicts Oceana Gold's dismissal of the Hikurangi risk based on distance. This indicates that Oceana Gold's assessment, as presented in the available documents, may not fully align with the most current and comprehensive best practices for seismic hazard assessment for TSFs in New Zealand. This is not merely a scientific disagreement but a potential issue of alignment with regulatory guidance, implying that the assessment might not be considered "robust" in the context of modern dam safety standards. The lack of detailed information on this specific aspect in their public reports further raises concerns about the completeness and transparency of their assessment.

Table 2 provides a comparison of Oceana Gold's stated MCE approach against the NZSOLD 2023 guidelines for High PIC dams.

4.13 Table 2: Comparison of Oceana Gold's MCE vs. NZSOLD Guidelines for High PIC Dams

Parameter	NZSOLD 2023 Requirements (for High PIC Dams)	Oceana Gold's Stated Approach (for Waihi TSFs)
Dam Classification (PIC)	High (based on consequence of failure)	(Likely High, based on consequence of failure of TSFs)
Operating Basis Earthquake (OBE) Return Period	1 in 150 AEP	Not explicitly stated in available information
Safety Evaluation Earthquake (SEE) Return Period	At least 1 in 2,500 AEP (not exceeding 1 in 10,000 AEP) [20]	Mw 7 at 9 km [6] (Implied MCE, not explicitly tied to a return period in available information)
Specific Consideration for Long-Period Ground Motions	"Careful consideration" due to TSF susceptibility	Dismissed due to "attenuation over distance" [User Query]

	to distant large magnitude events [20]	
Specific Consideration for Liquefaction/Lateral Spreading	"Thorough assessment" due to TSF susceptibility [20]	Tailings consolidate to "inherent shear strength" [6], implying static stability focus; dynamic liquefaction potential under MCE not explicitly detailed.
Consideration of Distant Large Magnitude Events	Explicitly mentioned as generators of concerning long-period motions [20]	Dismissed as "non-credible risks"

4.14 Potential Consequences of a Hikurangi Mw 9 Event at Waihi

4.14.1 Direct Impacts on TSF Structural Integrity

4.14.1.1 A Mw 9 Hikurangi event, even at a distance of over 200 km, could induce significant and sustained deformations in the Waihi TSF embankments due to the persistence and potential amplification of long-period ground motions.[8] This prolonged dynamic loading can lead to various forms of structural distress, including cracking of the embankment materials and a reduction in the dam's freeboard (the vertical distance between the water level and the crest of the dam).[6] Such damage could potentially result in overtopping of the dam, particularly if combined with heavy rainfall events, which the TSFs are designed to contain up to a 1200 mm rainstorm plus 1.0 m freeboard.[6] Furthermore, internal erosion, a process where fine particles within the dam body are washed out through cracks or permeable zones, could compromise the overall stability and integrity of the structure.[21]

4.14.2 Risk of Liquefaction-Induced Failure

4.14.2.1 The most catastrophic consequence for TSFs from seismic loading is flow liquefaction of the impounded tailings or the dam's foundation materials.[7] As discussed, distant mega-thrust earthquakes, characterised by their long duration and dominant long-period content, are highly effective at generating the sustained cyclic loading necessary to trigger liquefaction in susceptible, loose, saturated tailings.[12] A liquefaction-induced failure would result in a sudden and rapid loss of strength, causing the liquefied tailings mass to behave as a heavy liquid and leading to a flow slide.[19] This type of failure can be immediate during strong shaking or delayed, occurring hours or even a day after the main seismic event, as observed in the Mochikoshi dams case.[19]

4.14.3 Environmental and Safety Implications

4.14.3.1 The release of tailings from a TSF failure would have severe and widespread consequences. (see Section D) Tailings often contain hazardous substances, such as cyanide used in gold extraction and potentially acid-forming materials.[6] Their uncontrolled release would lead to significant environmental contamination of surrounding rivers, streams, and land, resulting in devastating long-term ecological impacts.[6] Beyond environmental damage, a flow slide of liquefied tailings poses an immediate and direct threat to human life and property. Such flows can travel significant distances, as exemplified by the Mochikoshi dam failure where tailings flowed over 800 meters.[19] This would endanger downstream communities, critical infrastructure, and agricultural land, potentially leading to significant casualties and extensive property damage.[7] The remediation of a large-scale tailings release is an extremely complex, costly, and time-consuming undertaking, often requiring decades and imposing lasting socio-economic burdens on the affected regions.

4.15 Recommendations for Enhanced Seismic Risk Management

To ensure the long-term safety and robustness of the Waihi Tailings Storage Facilities against the full spectrum of credible seismic hazards, particularly from the Hikurangi Subduction Zone, the following recommendations for an enhanced seismic risk management framework are proposed:

4.15.1 Propose a Comprehensive Seismic Hazard Assessment Framework for Waihi TSFs

- **Probabilistic Seismic Hazard Analysis (PSHA):** A site-specific PSHA should be conducted that explicitly includes the Hikurangi Subduction Zone as a major seismic source. This analysis should incorporate the latest research on the HSZ's Mw 9 potential and its diverse slip behaviors.[1] PSHA is essential as it combines contributions from all seismic sources to provide a comprehensive model of the earthquake hazard for the dam site, moving beyond a single deterministic MCE.[21]
- **Scenario-Based Ground Motion Modeling:** Detailed ground motion scenarios for a Mw 9 Hikurangi event at a distance of over 200 km should be developed. These scenarios must focus on ground motion parameters critical for TSF performance, including long-period spectral accelerations, peak ground velocities, and ground displacements, rather than solely peak ground acceleration.[13] This requires the use of advanced ground motion prediction equations (GMPEs) or numerical simulations

specifically calibrated to accurately capture long-period attenuation and the unique characteristics of distant subduction zone earthquakes.[16]

- **Site-Specific Response Analysis:** Comprehensive site response analyses are necessary to quantify the potential amplification of long-period motions by local geological conditions and engineered fill at the Waihi TSF site. This analysis should account for complex 3D basin effects, which can significantly alter the ground motion experienced at the surface.[13]
- **Non-linear Dynamic Analysis (NDA):** Non-linear dynamic analyses should be performed using sophisticated numerical models (e.g., finite element models) with appropriate constitutive models that accurately represent the behaviour of tailings materials under dynamic loading.[7] These analyses should simulate the TSFs' response to the derived long-period, long-duration ground motions, explicitly assessing deformation, pore pressure generation, and liquefaction potential under these specific loading conditions.[8]
- **Liquefaction Vulnerability Assessment:** A thorough and detailed assessment of liquefaction susceptibility is imperative for all potentially liquefiable materials within the TSFs and their foundations. This assessment must consider both the effects of peak shaking and the cumulative effects of long-duration shaking, which are particularly effective at triggering liquefaction.[19] This should include advanced laboratory testing of tailings materials to accurately characterize their dynamic properties.[7]

4.15.2 Emphasise Transparent Reporting and Ongoing Monitoring

4.15.2.1 All methodologies, assumptions, and results of the seismic hazard assessment should be clearly documented and made publicly available. This transparency is crucial for facilitating independent review by experts and fostering confidence among stakeholders and the public.[5] Furthermore, the existing comprehensive monitoring and surveillance program for the TSFs should be continuously maintained and enhanced. This includes integrating real-time data from instrumentation with 3D models to enable proactive risk management, particularly in response to seismic events or heavy rainfall.[5] While Oceana Gold's adoption of digital transformation for tailings management is a positive step [26], its effectiveness is contingent upon being underpinned by a truly robust and comprehensive seismic hazard assessment.

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5. Section C

1 Lessons from the Waitekauri (Golden Cross) Landslide for the Oceana Gold Waihi Tailings Storage Facility Fast Track Application

5.1. Introduction: Informing Critical Infrastructure Decisions

5.1.1. This section aims to extract and articulate essential lessons from the Waitekauri (Golden Cross) landslide, a significant historical event in New Zealand's mining landscape. These lessons are presented to directly inform the Fast-Track Panel's evaluation of the proposed Oceana Gold Waihi Tailings Storage Facility (TSF) expansion, with a particular focus on mitigating the inherent risks of dam breach due to seismic activity and extreme rainfall events.

5.1.1. Tailings storage facilities represent some of the largest engineered structures globally, designed for the long-term containment of vast quantities of mining waste, often requiring integrity "in perpetuity".[1] Despite their critical function, the failure rates of TSFs are notably higher than those of conventional water dams. Global estimates indicate a failure rate of approximately 1.2% for TSFs over the past century, significantly exceeding the 0.01% rate for water retention dams.[2] A substantial majority, over 90%, of these failures are attributed to active tailings dams.[4] This pronounced disparity underscores the imperative for exceptionally robust risk assessment, conservative design, and vigilant management, particularly in regions characterised by high seismicity and intense rainfall, such as the Coromandel Peninsula. The potential for catastrophic environmental damage, loss of life, and immense economic burden resulting from a tailings dam failure necessitates the application of the highest standards of due diligence and engineering practice.[1]

5.2 The Waitekauri (Golden Cross) Landslide: A Foundational Case Study

5.2.2 Historical Overview of Golden Cross Mine and its Tailings Facility

5.2.2.1 The Golden Cross gold mine is situated approximately eight kilometres northwest of Waihi, nestled within the Waitekauri Valley at the base of the Coromandel Peninsula.[9] The mine operated in two distinct phases: an initial period of gold mining activity from 1892/1895 to around 1917, and a more modern operation that commenced in 1991 and concluded in 1998.[10]

5.2.2.2 The geographical and geological setting of the Golden Cross site was a critical factor in its operational challenges. The area is characterised as a "sensitive high rainfall environment".[13] Crucially, the site's stability was significantly complicated by the presence of a "large ancient landslide underlying most of the tailings dam and waste rock".[15] This pre-existing geological instability meant that the tailings dam was constructed on a "slope of precarious stability".[16] The tailings dam itself was a substantial "large earth dam, approximately 70 m high," designed to retain an estimated 1.7 million cubic meters of tailings.[15] The downstream face of this dam was reportedly constructed from potentially acid-producing waste rock, which was encapsulated by a compacted layer of non-acid-producing andesitic material.[13]

5.2.2.3 The local geology of the Golden Cross site is composed of predominantly Miocene to Pliocene age andesitic and rhyolitic volcanics, which form a significant portion of the Coromandel Ranges. Key geological formations present at Golden Cross include the Omahia Andesite and the Union Volcanics. The Omahia Andesite is generally permeable, but exhibits "high permeability contrasts," meaning water flow through it can be highly variable. In contrast, the Union Volcanics are characterized by "high fracture permeability but low storativity," indicating that while water can move through fractures, the rock itself does not store large volumes of water.[15]

5.2.2.4 The repeated emphasis on the "large ancient landslide underlying most of the tailings dam" [15] and the "precarious stability" of the slope [16] points to a fundamental, inherent vulnerability of the site. Constructing a major long-term hydraulic structure like a TSF on such a known, large-scale geological instability introduces an elevated risk profile from the project's inception. This suggests that the initial site selection or the subsequent geotechnical understanding of the deep geological hazards was either insufficient or the long-term implications of building on an ancient landslide were underestimated.

5.2.2.5 The "sensitive high rainfall environment" [13] further exacerbates this, as water ingress directly impacts slope stability by increasing pore pressures. This highlights that for any proposed TSF, site selection and comprehensive pre-construction geological and geotechnical investigations are paramount. These investigations must extend well beyond the immediate dam footprint to thoroughly understand regional geological hazards, including ancient landslides and active fault lines. The principle that "the absence of identified structures in areas that have not been thoroughly investigated should not be used to conclude that structures do not exist" [17] is a critical guiding principle, emphasising the need for proactive, thorough, and potentially advanced investigation techniques to detect hidden geological weaknesses.

5.3 The 1996/1998 Landslide Event and its Immediate Consequences

5.3.1 In 1996, the Golden Cross mine faced a critical situation when a "major landslide under the Golden Cross tailings dam at Waitekauri near Waihi threatened to cause the dam to fail and spill its contents into the valley below". Evidence of ground movement had been observed as early as 1995 and 1996, manifesting as cracking in the shotcrete lining within the Southern Diversion Drain, ground cracking, the development of a tomo (a type of fissure) at the left abutment, and minor seepage zones.[15]

5.3.2 During the most active monitored period in the winter of 1996, recorded movement rates for the Lower Slide areas averaged between 2.8 to 4 mm per day, with daily rates occasionally surging up to 10 mm per day. Movement rates progressively decreased further upslope, indicating a "significant extension" of the landslide mass.[15] The instability was directly attributed to "water pressure" causing the ground beneath the pond to shift.[20] This aligns with the understanding that heavy rainfall is a common trigger for dam slides [21], as increased pore pressures reduce the effective stress and shear strength of the soil.[22]

5.3.3 The severity of the situation escalated to the declaration of a civil defence emergency. Ultimately, the Golden Cross mine was forced to cease operations permanently in 1998, a decision influenced by the landslip and prevailing low gold prices.[9] Coeur d'Alene Mines Corp., the operating company, recorded a substantial $53 million write-down in July 1996, indicating that the problem rendered the mine unprofitable and that the company could not recover its initial investment.[20] The company subsequently incurred nearly $30 million in costs for rectifying the problem.[9]

5.3.3 The direct link between "water pressure" [20] and the ground shift, coupled with the site's "high rainfall environment" [13], clearly establishes a causal relationship between hydrological conditions and geotechnical failure. High rainfall leads to increased pore water pressure, which in turn reduces the effective stress and shear strength of the soil, thereby triggering or reactivating landslides.[22] The pre-existing ancient landslide provided the susceptible failure plane, and water acted as the immediate trigger. The rapid movement rates (up to 10 mm/day) underscore the critical and urgent nature of such hydrological triggers. For the proposed Waihi TSF, this means that even with a seemingly stable foundation, extreme rainfall events pose a direct and severe threat to dam integrity by increasing pore pressures within the tailings and foundation, potentially leading to liquefaction or slope instability. The design must therefore robustly account for Probable Maximum Precipitation (PMP) [26] and its impact on pore water pressures, extending beyond mere dam overtopping prevention.

5.4 Engineering Response and Stabilisation Measures

5.4.1 The stabilisation of the Golden Cross landslide necessitated extensive "major drainage and earthworks".[15] A primary objective of these remedial works was the "lowering of piezometric levels within and around the head of the slide mass".[15] The methods employed to achieve this objective included the installation of "horizontal drainhole fans, pumping wells, and deep-subslide drainage".[15] Significant drainage was successfully achieved by strategically targeting the larger, relatively permeable andesite blocks within the Omahia Andesite geological formation.[15]

5.4.2 In addition to drainage, crack sealing earthworks were undertaken in two main areas of deformation where large cracks, up to 300 mm wide, had developed. The purpose of these works was to limit the ingress of surface runoff into the slide mass, thereby reducing the impact of rainstorm events by preventing the pressurization of tension cracks within the slide.[15]

5.4.3 Furthermore, the Tailings Storage Facility (TSF) itself was reconfigured as a wetland. This involved draining and rerouting water away from the TSF structure and planting native riparian vegetation.[11] This reconfiguration plan was initially part of the long-term post-closure strategy but its implementation was accelerated and brought forward due to the immediate instability of the dam.[11].

5.4.4 The extensive and costly stabilisation efforts at Golden Cross (exceeding $30 million) [9] were a reactive response to an existing catastrophic instability. The primary focus was on managing water (drainage, crack sealing, rerouting) and reconfiguring the TSF, essentially accelerating the planned closure. While these measures appear to have successfully stabilised the landslide at this time [15], this highlights the immense financial and operational burden of addressing a failure *after* it has occurred. The fact that the initial wetland reconfiguration plan was "brought forward" due to instability [11] underscores the reactive nature of the crisis management. For Oceana Gold at Waihi, this case study underscores the critical economic and safety imperative of *proactive*, highly conservative design and construction. Investing significantly in comprehensive geotechnical and hydrological studies, and incorporating robust, redundant drainage and stability measures *during* the initial design and construction phases, is demonstrably more cost-effective and safer in the long run than reacting to a catastrophic event.

5.5 Table 1: Chronology and Key Characteristics of the Golden Cross Landslide (1996-1998) and Stabilization Measures

Feature / Event	Description / Data	Source Snippets
Mine Operation Period (Modern)	1991-1998	[10]

Location	Waitekauri Valley, Coromandel Peninsula, 8 km NW of Waihi	[9]
Tailings Volume Retained	~1.7 million cubic meters	[15]
Dam Height	~70 meters	[13]
Key Geological Features	Underlain by a large ancient landslide; Omahia Andesite (permeable with high contrasts), Union Volcanics (high fracture permeability, low storativity)	[15]
Environmental Context	High rainfall environment, sensitive site	[13]
Triggering Event (1996)	Water pressure causing ground shift, exacerbated by high rainfall on a precariously stable slope	[13]
Landslide Movement Rates (Winter 1996)	Averaged 2.8-4 mm/day, up to 10 mm/day at times	[15]
Emergency Declared	Civil Defence Emergency	
Mine Status Post-Event	Forced permanent closure	[9]

Stabilization Costs	Over $30 million	[9]
Key Stabilization Methods	Major drainage (horizontal drainhole fans, pumping wells, deep-subslide drainage), crack sealing earthworks, water rerouting, TSF reconfiguration to wetland	[11]
Long-term Movement Post-Stabilization (Post-2001)	Reduced to 1.1-2.3 mm/yr	[15]

5.6 Critical Lessons Learned from Golden Cross for Tailings Dam Safety

5.6.1 The Paramountcy of Geotechnical Site Characterisation and Foundation Stability

5.6.1.1 The Golden Cross TSF was constructed on a site characterised by a "large ancient landslide" [15], inherently a "slope of precarious stability".[16] This pre-existing geological vulnerability meant the site was predisposed to instability from its inception. The underlying geological units, such as the Omahia Andesite and Union Volcanics, exhibit complex permeability characteristics.[15] While the Omahia Andesite is generally permeable, it possesses "high permeability contrasts," and the Union Volcanics are noted for "high fracture permeability but low storativity".[15] Such complexities can lead to unpredictable water flow patterns and localized pressure build-up within the ground.

5.6.1.2 General geotechnical principles affirm that the installation of a dam on a precariously stable slope can either initiate a new landslide or reactivate old failure surfaces.[16] Furthermore, insufficient bearing capacity of the underlying soil can precipitate critical failures, including punching shear or rotational shear failures.[16] The foundational problem at Golden Cross was not merely a design flaw of the dam itself, but the selection of a site with a pre-existing, large-scale ancient landslide.[15] This implies that the initial geological assessment either failed to fully identify the extent of this latent hazard or underestimated its long-term implications, especially when combined with the complex hydrogeological properties of the underlying rock. Landslides, particularly ancient ones, can be reactivated by changes in pore pressure or loading.[16]

5.6.1.2 This necessitates an approach that extends beyond standard geotechnical investigations focused solely on the dam footprint; it demands a comprehensive, regional understanding of rainfall patterns (both present and future projections due to climate change), geomorphology, historical geological processes, and deep subsurface conditions. The principle that "the absence of identified structures in areas that have not been thoroughly investigated should not be used to conclude that structures do not exist" [17] is a critical cautionary principle in this context. For the proposed Waihi TSF, this means geotechnical investigations must not only assess the immediate foundation of the dam but also conduct extensive regional studies. These studies must thoroughly identify any underlying ancient or active landslide features, previously unmapped fault lines, or complex hydrogeological conditions that could compromise long-term stability. This necessitates the use of advanced investigation techniques, such as high-resolution seismic imaging [27], to detect and characterize hidden geological weaknesses that traditional methods might miss.

5.6.2 Hydrological Vulnerability and Water Management

5.6.2.1 The Golden Cross site is situated in a "high rainfall environment" [13], a factor that proved pivotal in triggering the 1996 landslide. The instability was directly caused by "water pressure" shifting the ground beneath the dam.[20] This observation is consistent with global trends, where intense rainfall events are a significant trigger for tailings dam failures, with statistical studies indicating a concerning increase in such failures from 25% before 2000 to 40% after 2000.[29] This trend highlights a growing concern regarding hydrological risk in a changing climate.

5.6.2.2 The fundamental geotechnical mechanism at play is that increased water content leads to a rise in pore water pressure within the soil. This rise in pore pressure, in turn, reduces the effective stress and shear strength of the soil, making it highly susceptible to instability and liquefaction.[22] Tailings materials, due to their fine composition and inherently low hydraulic conductivity, consolidate slowly. This characteristic allows excess pore pressures to continuously build up within the dam, particularly in zones containing finer-grained "slimes".[22] The successful stabilisation of the Golden Cross landslide relied heavily on "major drainage works" and "crack sealing earthworks," specifically designed to limit surface runoff ingress and actively lower piezometric levels within the landslide mass.[15]

5.6.2.3 The observed global increase in tailings dam failures due to intense rainfall [29] is a critical trend. While the available information does not explicitly state climate change as the sole cause, the focus on "extreme rainfall event" aligns with projected climate change impacts, suggesting that historical rainfall data alone may no longer be sufficient for future risk assessment. The Golden Cross experience vividly demonstrates how water pressure, driven by high rainfall, can directly cause ground shift and instability.[20] This underscores that even with robust dam structures, inadequate water management can lead to catastrophic failure. The effectiveness of drainage systems [29] is paramount to regulating pore pressure and minimizing liquefaction risk.[29] Therefore, the design of the Waihi TSF must incorporate the most recent climate change projections for increased frequency and intensity of extreme rainfall events, not just historical averages. This necessitates more conservative estimates for Probable Maximum Precipitation (PMP) [26] and the implementation of robust, redundant, and continuously monitored surface water diversion and internal drainage systems capable of handling unprecedented volumes of water. The design must demonstrate how these systems will effectively maintain pore pressures below critical levels, especially in fine-grained tailings which retain water and consolidate slowly.

5.6.3 Seismic Hazard and Liquefaction Susceptibility

5.6.3.1 Tailings dams are intrinsically more susceptible to failure than conventional water dams, exhibiting a failure rate that is two orders of magnitude higher.[2] A major contributing factor to this elevated failure rate is seismic vulnerability, particularly the phenomenon of liquefaction. Tailings dams, especially those constructed using the upstream method, are highly prone to liquefaction-induced failures during seismic events.[2] Liquefaction occurs when the strength and stiffness of saturated soil abruptly drop to near zero as pore water pressure rapidly rises, causing the soil to behave like a heavy liquid.[23]

5.6.3.2 The 2015 Fundão dam collapse in Brazil serves as a critical modern case study that profoundly challenges traditional seismic design paradigms. This catastrophic event was preceded by *very small-magnitude earthquakes* (Mw 2.0-2.6) which acted as a "triggering mechanism" for a "liquefaction flow slide". This incident occurred despite the small magnitude of the seismic events, contradicting the long-held assumption that only larger quakes (e.g., above Mw 4.5) [32] pose a significant liquefaction risk. The Fundão dam was however an upstream-constructed facility, a method inherently prone to such failures.[31]

5.6.3.3 For the Waihi region, the seismic hazard should be significantly re-evaluated. (see Sections A and B) The Kerepehi Fault is an active normal fault capable of generating characteristic earthquakes ranging from Mw 5.5 to 7.0 for a single segment rupture, and potentially up to Mw 7.2-7.4 if all onshore segments rupture simultaneously.[33]

5.6.3.4 Furthermore, the Hikurangi Subduction Zone, located off the East Coast of the North Island, is identified as potentially the largest source of earthquake and tsunami hazard in New Zealand. This zone has the capacity to produce large (M > 7) to great (M > 8) "megathrust" earthquakes.[34] While "slow slip events" on this zone are not felt at the surface, they can trigger small earthquakes and are driven by the same underlying forces as large, damaging seismic events.[34]

5.6.4 The "Perfect Storm" Scenario: Compounding Natural Hazards

5.6.4.1 A critical concern is the potential for a "high-intensity tropical storm" to saturate the tailings, which, if followed quickly by an earthquake, could create a "liquefaction flow slide – a 'perfect storm'". This concept highlights a critical failure pathway where the interaction of multiple natural hazards creates a risk significantly greater than the sum of its individual parts. General understanding of earthquake impacts suggests that their consequences are amplified if communities or infrastructure are already under stress from climate change-exacerbated events such as drought and flooding.[37] The Kaikoura earthquake, which unleashed thousands of landslides, provides a stark example of the vulnerability of saturated slopes to seismic triggers.

5.6.4.2 The "perfect storm" concept is not merely a hypothetical worst-case; it represents a critical failure pathway where the interaction of multiple natural hazards creates a risk significantly greater than the sum of its parts. Individual hazard assessments (e.g., for earthquake, for rainfall) are insufficient if they do not account for their compounding effects. Extreme rainfall can lead to saturation of tailings, increasing pore pressure and reducing shear strength. A subsequent earthquake, even a small one, can then trigger liquefaction in these already weakened, saturated materials. This is a synergistic effect where one condition (saturation) dramatically amplifies the destructive potential of another (seismic shaking).

5.6.4.3 Therefore, Waihi's TSF design and risk assessment must explicitly model *cascading failure scenarios* where extreme rainfall amplified by more intense events due to climate change and seismic events occur in close temporal proximity. This requires advanced, integrated hydrogeological and geotechnical modeling that captures the dynamic changes in tailings properties (e.g., saturation, pore pressure) due to rainfall and then assesses the seismic response under those altered, more vulnerable conditions. This integrated approach is vital for true resilience.

5.6.5 Long-Term Environmental and Financial Liabilities

5.6.5.1 Tailings dams are unique structures that "must stand in perpetuity" [1], meaning their structural and environmental integrity must be maintained indefinitely, long after mining operations cease. The failure of these dams invariably leads to "long-term environmental damage with huge cleanup costs".[1] (see Section D) Tailings are not inert materials; they are "potentially toxic" [7] and frequently contain hazardous substances, including heavy metals and beneficiation agents.[3]

5.6.5.2 Contamination of surrounding soil, surface water, and groundwater represents a major and persistent risk.[39] Once contaminants migrate through the unsaturated zone into the groundwater zone, their rate of lateral movement increases by orders of magnitude, significantly extending the potential environmental impact spatially and temporally.[40] Acid Mine Drainage (AMD), a common pollutant from tailings dams, is caused by the oxidation of sulphide-bearing rock and can be enhanced by biological processes. This AMD can continue to adversely affect the environment for "hundreds of years".[41]

5.6.6.3 The Golden Cross case specifically highlighted deficiencies in financial provisioning for long-term liabilities. The mine's environmental bond was believed to be $12 million , yet the actual stabilisation costs exceeded $30 million.[9] This significant disparity strongly implies that taxpayers would likely bear most of the costs of a future failure. In New Zealand, the responsibility for long-term maintenance and damage repair following the expiry of water rights is "not prescribed by law" [41], meaning abandoned sites may, by default, become the responsibility of the Crown.[41] Furthermore, tailings can take "tens of years after mine closure to consolidate" [41], extending the period of vulnerability and the need for active management.

5.6.6.4 The concept of "perpetuity" for TSFs [1] combined with the multi-century duration of some environmental impacts like AMD [41] and the slow consolidation of tailings (tens of years) [41] reveals a profound intergenerational liability. The financial bond for Golden Cross ($12M) was clearly insufficient for the actual stabilization costs ($30M) [9], demonstrating a systemic underestimation of long-term liabilities. The absence of clear legal responsibility for post-closure maintenance in New Zealand [41] means that society, rather than the mining company, bears the ultimate, potentially perpetual, cost and risk. This implies that current financial and legal frameworks are grossly inadequate for the scale and duration of the environmental threat.

5.7 Application to Oceana Gold's Waihi Tailings Storage Facility and Future Planning

Updated Seismic Risk for Waihi (See Sections A and B)

5.7.1 Extreme Rainfall and Liquefaction Potential at Waihi

5.7.1.1 The Waihi TSF is designed to contain a 1200 mm rainstorm (Probable Maximum Precipitation, PMP) plus an additional 1.0 meter minimum freeboard [26], indicating that consideration has been given to extreme rainfall events. Tailings are pumped as a slurry into the impoundments [26], a deposition method that makes them potentially susceptible to seismic or flow liquefaction unless adequately compacted, consolidated, and desiccated.[2] While specific geotechnical properties of Waihi tailings are not detailed in all available information, general tailings characteristics often include fine-grained materials such as "silty clay material" with "low plasticity" [21], which are known to be prone to liquefaction. Tailings also typically exhibit low density and low shear modulus, contributing to a long natural vibration period of the dam body, which can increase their susceptibility to seismic liquefaction.[5]

5.7.1.2 Waihi's TSF employs various drainage systems, including underdrains beneath the tailings, an upstream cutoff drain, initial and downstream toe drains, gully subsoil drains, and leachate collection drains. Diversion drains are also in place to intercept clean surface runoff from adjacent hillsides.[26] Monitoring activities include measurements of supernatant decant pond water volumes and levels, as well as freeboard.[42]

5.7.1.3 While Waihi's TSF design includes provisions for Probable Maximum Precipitation [26], the Golden Cross experience [20] and broader literature [22] demonstrate that high rainfall can still lead to instability by increasing pore pressures and reducing effective stress, especially in fine-grained, low-permeability tailings. The effectiveness of drainage systems [29] is critical, but tailings' slow consolidation and low hydraulic conductivity [22] mean that excess pore pressures can accumulate. The presence of "silty clay material" [21] and "low plasticity" further suggests inherent liquefaction susceptibility.[23] The "residual level of saturation" [1] in tailings, even in "free draining" dams, can still lead to liquefaction if triggered. The Fast-Track Panel needs robust assurance that Waihi's drainage systems are not only designed for PMP but are demonstrably *effective* in actively maintaining pore pressures below critical levels under extreme rainfall conditions projected to become even more extreme under the most recent climate change projections, particularly given the specific characteristics of the Waihi tailings. This requires detailed and dynamic modeling of drainage efficiency and its impact on stability [29], moving beyond static design considerations to a continuous, performance-based assessment.

5.8 Enhancing Long-Term Stability and Oversight

5.8.1 Oceana Gold reports a "comprehensive monitoring and surveillance program" for its existing Storage 1A and 2, which is detailed in an Operations, Maintenance and Surveillance Manual.[42] This manual is regularly updated to comply with New Zealand Dam Safety Guidelines (NZDSG), with further updates scheduled for 2024.[42] Monitoring activities include visual inspections, measurements of supernatant decant pond water volumes and levels, freeboard measurements, and oversight of materials and construction standards.[42] The data collected from this program is provided annually to the Waikato Regional Council and Hauraki District Council and undergoes independent peer review by a Peer Review Panel (PRP) engaged by Oceana Gold.[42]

5.8.2 Oceana Gold is also actively piloting a "digital twin" technology for proactive monitoring of slope stability at Waihi. This advanced system integrates vast amounts of siloed data, including sensor readings and real-time Internet of Things (IoT) data, to provide critical insights into core pressure and groundwater levels. This allows for dynamic risk management and proactive action following events such as significant rainfall.[43] The digital twin system also facilitates easy access to historical models and audit trails, enhancing transparency and accountability.[43]

5.8.3 Globally, the mining industry, through organizations like the International Council on Mining and Metals (ICMM), has developed updated guidance (published in 2025) on tailings management and closure. This guidance emphasizes early planning, strong governance, and progressive closure activities to ensure long-term stability. ICMM members are committed to implementing the Global Industry Standard on Tailings Management (GISTM) -- but has Oceana Gold confirmed membership of ICMM and adherence to the guidelines? .[44]

5.8.4 Despite these advancements global statistics consistently show that tailings dam failures continue to occur at a relatively constant rate. These failures are often linked to "apparent deficiencies in design, operation and management which are repeated".[1] Human error is also acknowledged as a contributing factor in these incidents.[6] A key point of contention locally regarding the Waihi operations is the independence of the peer review process. While Waikato Regional Council staff express confidence in the current annual peer review, critics advocate for a truly independent review, arguing that it should not be appointed by the company itself.

5.8.5 The broader literature consistently highlights that even with "improved technology for design, construction and operation," tailings dam failures still occur due to "apparent deficiencies in design, operation and management which are repeated".[1] This suggests a critical gap between documented procedures and actual, demonstrable resilience, potentially stemming from human error, the protracted nature of TSF construction over multiple staff/ownership changes, or a focus on compliance rather than genuine, proactive risk mitigation. The call for *independent* peer review directly addresses this potential for unconscious bias or conflict of interest in assessments.

5.9 Table 2: Key Risk Factors and Mitigation Strategies: Golden Cross Lessons Applied to Waihi TSF

Risk Factor (from Golden Cross)	Lesson Learned (from Golden Cross)	Application/Mitigation Strategy for Waihi TSF
Construction on Ancient Landslide / Precarious Slope [15]	Thorough, regional geotechnical investigation is essential to identify and characterise all deep-seated geological vulnerabilities.	Mandate comprehensive, independent deep-seated geological/geotechnical surveys for all TSF footprints, extending beyond immediate dam area.
High Rainfall / Water Pressure Buildup [13]	Robust, active water management is critical to control pore pressure and prevent instability, especially in high rainfall environments.	Require integrated hydrogeological modeling for extreme rainfall events (including most recent climate change projections) and robust, redundant drainage systems to maintain critical pore pressure levels.

Liquefaction Susceptibility [2]	Tailings liquefaction potential must be rigorously assessed for all seismic events, regardless of magnitude.	Demand updated liquefaction analyses for all TSFs, considering the full spectrum of seismic events from very small to large, and their specific impacts on saturated tailings.
Small-Magnitude Earthquake Trigger (Brazil case, relevant for Waihi)	Very small, proximal earthquakes can be catastrophic triggers for liquefaction flow slides in susceptible dams.	Explicitly model and mitigate risks from low-magnitude, high-frequency, proximal seismic triggers in design and operational protocols.
Inadequate Long-Term Financial/Legal Provisions	Perpetual financial and legal provisions are non-negotiable for TSFs, covering indefinite environmental and social liabilities.	Require robust, periodically reviewed financial bonds and legal frameworks that genuinely cover the perpetual environmental and social liabilities of the TSF, preventing taxpayer burden.

5.10 Recommendations for the Fast-Track Panel's Decision-Making

Based on the critical lessons derived from the Waitekauri (Golden Cross) landslide and the broader understanding of tailings dam safety, the following recommendations are put forth for the Fast-Track Panel's consideration regarding the Oceana Gold Waihi application:

5.10.1 Recommendation 1: Mandate a Comprehensive, Independent Seismic Re-assessment

The Panel must require an immediate, comprehensive, and *independent* seismic hazard assessment for *all* Waihi TSFs (existing Storage 1A, 2, and proposed Storage 3). This assessment must fully integrate the latest peer reviewed studies on the Kerepehi / Te Puninga fault (see Sections A and B). It must also account for the potential for large "megathrust" earthquakes (M>7-8) from the Hikurangi Subduction Zone, identified as New Zealand's largest source of earthquake and tsunami hazard. (see Section B) [34] Crucially, the re-assessment must explicitly model and address liquefaction potential under these revised seismic parameters, including the impact of *small-magnitude, proximal earthquakes* (Mw 2.0-2.6) as demonstrated by the 2015 Brazil dam collapse. The review must be conducted by experts *not* appointed by Oceana Gold to ensure complete impartiality and avoid any perceived conflict of interest. This recommendation directly addresses the core contradiction identified: the existing Waihi TSF design relies on outdated seismic data, while new scientific understanding significantly increases the perceived hazard for the region. This is not a static risk; it dynamically evolves with new scientific insights. The emphasis on *independence* for the re-assessment is crucial to overcome potential biases inherent in company-appointed reviews. Regulatory bodies must establish robust mechanisms for continuous, mandatory re-evaluation of seismic hazards for critical infrastructure, ensuring that designs are updated to reflect the latest scientific understanding. This includes considering the full spectrum of potential seismic events, from frequent small tremors to less frequent large quakes, and their combined effects.

5.10.2 Recommendation 2: Require Robust Hydrogeological and Geotechnical Due Diligence

The Panel should insist on an independent, in-depth review of the Waihi TSF's foundation stability, internal drainage systems, and pore pressure management strategies. This review must specifically assess the dam's performance under *combined extreme rainfall and seismic scenarios*, explicitly modeling the "perfect storm" potential where saturated tailings are subjected to earthquake shaking. It should verify the effectiveness of the drainage systems in actively maintaining pore pressures below critical levels, particularly given the specific geotechnical properties of Waihi tailings (e.g., silty clay, low plasticity) [21] and the likelihood of a "residual level of saturation".[1] The Golden Cross landslide was fundamentally a hydrogeological failure exacerbated by pre-existing instability.[15] The global trend of increased rainfall-induced failures [29] reinforces the escalating nature of this risk. Therefore, assessing hydrological and seismic hazards in isolation is insufficient. The synergistic interaction between water saturation (from extreme rainfall) and seismic shaking (triggering liquefaction) represents a critical and potentially catastrophic failure pathway that must be explicitly modeled and mitigated. Integrated hazard modeling, which considers the compounding and cascading effects of multiple natural phenomena, should become a mandatory standard requirement for TSF design and risk assessment. This moves beyond siloed analyses to a holistic understanding of system vulnerability.

5.10.3 Recommendation 3: Strengthen Independent Oversight and Regulatory Frameworks

To ensure the highest level of safety and public confidence, all TSF design, construction, operation, and monitoring data, including the output from Oceana Gold's digital twin system, must be subject to continuous, *truly independent* peer review. This means that the Peer Review Panel (PRP) should be engaged and directly accountable to the regulatory authority (e.g., Waikato Regional Council, Hauraki District Council), rather than being appointed by Oceana Gold. Clear, legally binding mechanisms for regulatory intervention, based on identified risks from these independent reviews, must be established, enforced, and publicly transparent. While Oceana Gold's internal monitoring and adoption of advanced technologies like digital twins [43] are positive, the ultimate responsibility for public and environmental safety rests with the regulators. A peer review panel engaged directly by the company, no matter how competent, can be perceived as lacking full independence, potentially leading to less conservative assessments or slower adoption of new scientific findings. True independence fosters public trust and ensures a more critical, unbiased assessment of risk. Regulatory frameworks for high-hazard facilities must mandate independent oversight at all stages, from initial design through to post-closure. This independence should extend to the appointment and reporting lines of review panels, ensuring that their primary accountability is to the public interest and safety, rather than the project proponent's commercial objectives.

5.10.4 Recommendation 4: Secure Perpetual Financial and Legal Provisions

The Panel must require robust financial bonds and legal frameworks that explicitly cover the *perpetual* environmental and social liabilities of the Waihi TSF, extending indefinitely beyond mine closure. This provision must realistically account for the long-term nature of tailings consolidation (tens of years) and the potential for Acid Mine Drainage (AMD) generation (hundreds of years).[41] The bond amount must be periodically reviewed and adjusted to reflect the true, evolving costs of potential long-term failures, ensuring that the taxpayer is not burdened with the financial consequences of a future incident. The concept of "perpetuity" for TSFs [1] combined with the multi-century duration of some environmental impacts like AMD [41] and the slow consolidation of tailings (tens of years) [41] reveals a profound intergenerational liability. The financial bond for Golden Cross ($12M) was clearly insufficient for the actual stabilization costs ($30M) [9], demonstrating a systemic underestimation of long-term liabilities. The absence of clear legal responsibility for post-closure maintenance in New Zealand [41] means that society, rather than the mining company, bears the ultimate, potentially perpetual, cost and risk. This implies that current financial and legal frameworks are grossly inadequate for the scale and duration of the environmental threat.

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6 Section D

Environmental and Socio-Economic Impacts Downstream of Paeroa of a Tailings Dam Breach

6.1 Executive Summary

6.1.1 Oceana Gold's dam breach assessment for the proposed Storage 3 Tailings Storage Facility (TSF) at Waihi identifies "catastrophic" impacts on major infrastructure and the natural environment up to the town of Paeroa, leading to a "High Potential Impact Classification". However, the study's critical limitation lies in its termination of flood routing and impact assessment immediately downstream of the Ohinemuri River's confluence with the Waihou River. This omission leaves unaddressed the potential for widespread, long-term ecological and socio-economic devastation to the Waihou River, the already degraded Firth of Thames, and the ecologically sensitive Hauraki Gulf. Drawing parallels with the catastrophic 2015 Fundão tailings dam breach in Brazil, which saw toxic tailings travel hundreds of kilometers to the Atlantic Ocean, causing profound river and marine ecosystem collapse and severe socio-economic disruption, it is evident that a comprehensive "source-to-sea" assessment is imperative for a project of this scale. The current assessment, by failing to model and evaluate these downstream and marine impacts, does not meet contemporary best practice for robust environmental risk assessment for large-scale tailings facilities.

6.2 Introduction

6.2.1 The responsible management of mining tailings, particularly in seismically active and high-rainfall regions, demands an exhaustive understanding of potential failure consequences. This critique focuses on the environmental, social, and economic impact assessment presented by Oceana Gold for a hypothetical breach of its Storage 3 TSF. This review specifically evaluates the robustness of the study's conclusions, considering its geographical scope and drawing upon critical lessons from international tailings dam failures, such as the Fundão disaster in Brazil. The objective is to ascertain whether the presented assessment adequately captures the full spectrum of risks to the Ohinemuri River, its tributaries, the Waihou River, the Firth of Thames, and the wider Hauraki Gulf marine environment.

6.3 Review of Oceana Gold's Dam Breach Assessment: Scope and Findings

6.3.1 Oceana Gold's assessment correctly identifies the Ohinemuri River and its tributaries, including the Ruahorehore Stream, as the primary receiving watercourses for a potential tailings dam breach. The report models both "Sunny Day" (normal conditions) and "Rainy Day" (extreme rainfall, 1-in-1000 year flood) breach scenarios, concluding that the "Rainy Day" scenario presents the maximum incremental consequences. Under this scenario, the assessment projects "catastrophic" impacts on major infrastructure and the natural environment, and "major" impacts on residential dwellings and community recovery time, which is assessed in "years". Specifically, it anticipates:

- **Inundation:** Overtopping of stopbanks in Paeroa, leading to shallow flooding, and incremental flooding along the Ruahorehore Stream, Ohinemuri River flood channel, southern Waihi township, Karangahake Gorge, and adjacent farmland.
- **Infrastructure Damage:** Significant damage to Storage 3 itself (over a year for repair), potential destruction of Baxter Road Bridge, Waikino Railway Bridge, and Waitawheta Road Bridge, and significant damage to sections of State Highway 2 (SH2). Localised overtopping and erosion of Ohinemuri River stopbanks near Paeroa are also anticipated.
- **Natural Environment:** "Major" and "catastrophic" incremental impact on the natural environment, requiring costly and time-consuming restoration of the Ohinemuri River, adjacent farmland, and Ruahorehore Stream. The impacted area is noted to be significantly wider than a "Sunny Day" breach, including Gilmour Reserve and 20 hectares in Paeroa township.
- **Social, Cultural, and Economic Impacts:** Damage to the Karangahake Gorge Historical Walkway (tourism impacts), significant cultural impact for Māori due to water contamination (water as a taonga), and major economic impacts for OGNZL, employees, and the Waihi community due to potential cessation or reduction in mining. Farms using Ohinemuri River water for irrigation would also face economic effects.

6.3.2 While these findings are stark and deemed “catastrophic”, the fundamental flaw in the assessment's robustness lies in its geographical boundary. The report explicitly states that its flood routing model is "terminated immediately upstream of the confluence of the Ohinemuri River and Waihou River". This means that the potential impacts on the Waihou River, the Firth of Thames, and the wider Hauraki Gulf marine environment are not quantitatively assessed or even qualitatively discussed in detail.

6.4 The Critical Omission: Downstream Ecological and Socio-Economic Impacts Beyond Paeroa

6.4.1 The Ohinemuri River flows directly into the Waihou River, which then discharges into the Firth of Thames. The Firth of Thames is already recognized by the Waikato Regional Council as a "degraded water body." This critical hydrological connection means that any tailings breach, even if its immediate catastrophic physical impacts are contained to Paeroa, would inevitably transport a massve volume of sediment and toxic contaminants further downstream into these sensitive river, estuarine and marine environments.

The absence of detailed assessment for these downstream areas represents a profound gap in the study's robustness:

6.4.2 **Ecological Impacts on Waihou River and Firth of Thames:** The Waihou River, as a major conduit, would experience severe sedimentation, altering its morphology, smothering benthic habitats, and impacting fish and invertebrate populations. Upon reaching the Firth of Thames, the fine-grained tailings, potentially containing acid-forming materials and mobilized heavy metals (as the ore is noted to contain PAF material), would introduce chronic pollution. This could lead to:

- **Smothering:** Direct physical smothering of seagrass beds, shellfish beds, and other critical intertidal and subtidal habitats.
- **Turbidity:** Prolonged high turbidity, reducing light penetration and impacting photosynthetic organisms at the base of the food web.
- **Contamination:** Bioaccumulation and biomagnification of heavy metals (e.g., arsenic, lead, mercury, chromium, nickel, manganese, as seen in other tailings disasters) within the food chain, threatening fish, shellfish, and marine mammals.
- **Ecosystem Collapse:** Disruption of delicate estuarine and marine food webs, potentially leading to localized or widespread ecosystem collapse, especially given the existing degraded status of the Firth.

6.4.3 **Impacts on Hauraki Gulf Marine Environment:** The Hauraki Gulf, a significant marine protected area and a vital ecological and economic asset, is the ultimate recipient of waters from the Firth of Thames. The long-distance transport of fine tailings particles and dissolved contaminants could extend impacts far into the Gulf, affecting:

- **Biodiversity Hotspots:** The RAMSAR reserve of international significance in the southern Firth of Thames, sensitive habitats like sea grass, sponge gardens, and fish spawning grounds.
- **Endangered Species:** Threatening endangered marine species through habitat degradation and bioaccumulation.

6.4.4 **Socio-Economic Impacts:** The unassessed downstream impacts would have severe socio-economic consequences:

- **Fisheries:** Collapse of commercial and recreational fisheries in the Waihou River, Firth of Thames, and potentially parts of the Hauraki Gulf due to habitat destruction, fish die-offs, and contamination, leading to significant livelihood losses.
- **Aquaculture:** Impacts on aquaculture operations (e.g., mussel farms and fish farming) within the Firth of Thames and Hauraki Gulf.
- **Tourism and Recreation:** Damage to coastal tourism and recreational activities (boating, swimming, birdwatching) due to pollution and aesthetic degradation.
- **Cultural Values:** Further profound impacts on Māori cultural values, as the marine environment is deeply intertwined with their identity, traditional practices, and spiritual well-being.

6.4.5 Oceana Gold's assessment of a 1-in-1,000 year dam breach at Waihi forecasts "catastrophic" impacts on infrastructure and environment, with "major" residential damage and multi-year recovery, including 200 people at risk and two potential fatalities.[1] Crucially, this analysis largely omits downstream impacts on the Waihou River, Firth of Thames, and Hauraki Gulf. The 2015 Fundão disaster in Brazil, where toxic tailings traveled hundreds of kilometers, devastated marine ecosystems and affected 1.6 million people, leading to a $32 billion settlement.

6.4.6 A Waihi breach reaching the Hauraki Gulf could trigger comparable, unquantified costs. This would likely exceed New Zealand's costliest natural disasters, such as the combined Cyclone Gabrielle and Auckland Anniversary floods ($9-14.5 billion), representing an unprecedented environmental and socio-economic catastrophe for the nation with costs and recovery timelines likely eclipsing previous national disasters.

6.5 Lessons from the Fundão Tailings Dam Breach, Brazil

6.5.1 The 2015 Fundão tailings dam breach in Mariana, Brazil, serves as a stark, real-world illustration of the devastating, far-reaching consequences of a tailings dam failure that extends into marine environments. This disaster provides critical insights into the potential scale of unassessed impacts for the Waihi operation:

- **Massive Release and Riparian Devastation:** The Fundão dam released an estimated 43.7 to 62 million m³ of toxic tailings. This torrential flood engulfed villages, destroyed hundreds of buildings, and obliterated 1,469 hectares of forest along 77 km of waterways.
- **Widespread Contamination:** The toxic sediment carried heavy metals, including arsenic, lead, mercury, chromium, nickel, and manganese. Concentrations in water, sediments, fish, and shrimp exceeded safety limits by dozens or even hundreds of times.
- **Riverine and Marine Ecological Catastrophe:** The plume traveled over 650 to 700 km downstream, reaching the Atlantic coast. It caused massive fish die-offs (14 tons in freshwater, nearly 29,000 carcasses near the ocean) and polluted estuaries, reefs, and marine protected areas, including the highly biodiverse Abrolhos National Marine Park. Marine impacts included the smothering of coral reefs, seagrass beds, and benthic organisms by iron-rich sediment, increased turbidity, and bioaccumulation threatening higher trophic levels and endangered species. Scientists warned that recovery could take decades.
- **Profound Socio-Economic Disruption:** The disaster triggered a water crisis for over 250,000 residents, led to the collapse of fishing communities' livelihoods, and affected more than 1.6 million people socially and economically. The owners faced a $US 32 billion settlement for environmental restoration and social compensation.
- **Protracted Recovery:** Environmental recovery has been slow, hindered by persistent heavy metals and altered river morphology, with full restoration potentially taking generations.

6.5.2 While the volume of tailings at Waihi (e.g., 1.976 Mm³ for a Rainy Day breach) is smaller than Fundão, the *nature* of the potential contaminants (PAF material) and the *pathway* to a sensitive marine environment (Firth of Thames, Hauraki Gulf) are strikingly similar. The Fundão disaster unequivocally demonstrates that the impacts of a tailings breach are not confined to the immediate downstream river sections but can extend hundreds of kilometers, causing profound and long-lasting damage to marine ecosystems and the communities reliant upon them.

6.5.3 Oceana Gold's assessment of a 1-in-1,000 year dam breach at Waihi forecasts "catastrophic" impacts on infrastructure and environment, with "major" residential damage and multi-year recovery, including 200 people at risk and two potential fatalities.[1]. The 2015 Fundão disaster in Brazil, where toxic tailings traveled hundreds of kilometers, devastated marine ecosystems and affected 1.6 million people, leading to a $US 32 billion settlement. A Waihi breach reaching the Hauraki Gulf could trigger comparable, unquantified costs. This would likely exceed New Zealand's costliest natural disasters, such as the combined Cyclone Gabrielle and Auckland Anniversary floods ($9-14.5 billion), representing an unprecedented environmental and socio-economic catastrophe for the nation with costs and recovery timelines likely eclipsing previous national disasters.

6.6 Robustness of the Study and Best Practice

6.6.1 Given the lessons from Fundão and the direct hydrological connection to the Waihou River, Firth of Thames, and Hauraki Gulf, Oceana Gold's current dam breach assessment is not robust. Best practice for assessing the environmental and socio-economic risks of critical infrastructure like tailings dams demands a comprehensive "source-to-sea" or "source-to-receptor" analysis. This includes:

- **Full Hydrological Modeling:** The modeling should extend to the ultimate receiving waters, accurately simulating the transport and dispersion of tailings and associated contaminants throughout the entire river and marine system.
- **Detailed Ecological Risk Assessment:** This must go beyond general statements of "significant but recoverable" damage to include specific assessments of impacts on marine flora and fauna, benthic communities, and sensitive habitats within the Firth of Thames and Hauraki Gulf. This requires baseline ecological data for these areas.
- **Contaminant Transport and Fate:** A thorough analysis of the potential for heavy metal mobilisation from the tailings (noted to be PAF) and their transport, deposition, and bioaccumulation in the marine environment is essential.
- **Long-Term Recovery Projections:** Realistic projections for environmental recovery, acknowledging that full restoration of complex marine ecosystems can take decades or even generations, as demonstrated by Fundão.
- **Comprehensive Socio-Economic Impact Assessment:** A detailed evaluation of the impacts on all affected stakeholders, including commercial and recreational fisheries, tourism, and Māori cultural values, extending to the marine environment.

6.6.2 The current assessment, by terminating its modeling at Paeroa, implicitly dismisses the potential for significant impacts on these critical downstream environments. This approach is inconsistent with the scale of potential consequences and falls short of the rigorous standards required for a project with a "High Potential Impact Classification."

6.7 Conclusions and Recommendations

6.7.1 The assessment of a tailings dam breach is fundamentally incomplete and therefore not robust. The failure to model and assess the consequences beyond Paeroa, particularly for the Waihou River, the Firth of Thames, and the Hauraki Gulf, represents a critical oversight. The catastrophic and far-reaching impacts of the Fundão disaster serve as a stark reminder of the potential for widespread ecological and socio-economic devastation when such comprehensive assessments are lacking.

6.7.2 Recommendations:

1. **Extended Dam Breach Modeling:** Mandate a comprehensive dam breach modeling exercise that extends the flood routing and contaminant transport simulations through the entire Waihou River system, into the Firth of Thames, and across the Hauraki Gulf. This modeling must account for the physical dispersion of tailings and the transport of dissolved contaminants.
2. **Detailed Marine Ecological Impact Assessment:** Require a dedicated, in-depth ecological impact assessment for the Firth of Thames and the Hauraki Gulf. This assessment should include:
    - Baseline studies of key marine habitats (e.g., seagrass beds, shellfish beds, intertidal zones) and wading birds and other threatened or endangered species. (RAMSAR)
    - Specific modeling of sediment deposition patterns and their physical impacts.
    - Analysis of heavy metal mobilisation from tailings and their potential for human and non-human bioaccumulation and biomagnification within marine food webs.
    - Assessment of impacts on marine biodiversity, including endangered species.
    - Realistic long-term recovery projections, acknowledging the potential for multi-decade or generational timescales.
3. **Comprehensive Socio-Economic Impact Assessment for Coastal Communities:** Conduct a detailed socio-economic impact assessment that

specifically addresses the potential consequences for fishing communities, aquaculture operations, fish farming, tourism, and recreational users within the Firth of Thames and Hauraki Gulf. This must also include a thorough evaluation of impacts on Māori cultural values associated with these marine environments.

4. **Development of Marine-Specific Mitigation and Remediation Plans:** Based on the extended impact assessments, develop detailed, actionable mitigation and remediation plans specifically tailored for marine environments, drawing upon lessons learned from international tailings dam failures.
5. **Re-evaluation of Potential Impact Classification:** Re-evaluate the "Potential Impact Classification" for the Storage 3 TSF based on the full, comprehensive assessment of environmental, social, and economic consequences extending to the marine environment.

Only through such a comprehensive and transparent assessment can the true risks of a tailings dam breach be understood and adequately managed, ensuring the long-term protection of New Zealand's precious natural heritage and the well-being of its communities.

6.8 References

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