Proposed Wharekirauponga Underground Mine

Native Frog Effects Assessment

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Cover Illustration: Hochstetter's frog (*Leiopelma hochstetteri*) in streamside habitat. Image not taken in Wharekirauponga.

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1 EXECUTIVE SUMMARY

Bioresearches was engaged by OceanaGold (New Zealand) Limited (OGNZL) to undertake an assessment of the ecological effects on native frogs in relation to the proposed Wharekirauponga Underground (WUG) Mine, which forms part of the Waihi North Project.

Activities associated with construction and operation of the Wharekirauponga Underground Mine such as blasting and dewatering, have been identified as potential risks to populations of Archey's frog (*Leiopelma archeyi*) and Hochstetter's frog (*Leiopelma hochstetteri*) that inhabit the forests and streams above the proposed mine. Specifically, seismic vibrations from underground blasting, that propagate through the rock mass to the surface could disturb frogs over an area of approximately 315 ha. Hydrological modelling has predicted potential surface water impacts in the form of baseflow reductions in streams within the Wharekirauponga catchment due to dewatering associated with the Wharekirauponga Underground Mine. Baseflow reductions and associated effects on instream habitat could potentially impact semi-aquatic Hochstetter's frogs that live on the edges of forested streams.

This report adopts an integrated approach to assessing the potential effects of vibration and dewatering on native Leiopelmatid frogs. It combines detailed literature reviews and fauna database analyses with reviews of technical reports across engineering, hydrology, ecology, and biostatistics. Additionally, information from recent field surveys has been incorporated to improve knowledge on *Leiopelma* frog distribution and abundance, and allow an evidence based assessment of potential effects to be presented.

A summary of the report's findings includes:

- Leiopelmatid frogs represent a unique evolutionary lineage among amphibians and have high conservation value in New Zealand and worldwide.
- Two species—Archey's frog and Hochstetter's frog—are known to occupy the forests and streams above the Wharekirauponga Underground Mine footprint. Both are legally protected, and both are in decline.
- Archey's frog is terrestrial and Hochstetter's frog is semi-aquatic; the latter requires water to complete their reproductive cycle.
- Potential ecological impacts of frogs, associated with the proposed Waihi North Project, include:
    - Surface vibration due to blasting – the vibrations experienced are unlikely to result in measurable effects on Archey's or Hochstetter's frog populations occupying the forests above the proposed Wharekirauponga Underground Mine or across the Coromandel Range because:
        - Vibration footprints cover a small proportion of the total area occupied by native frogs in Wharekirauponga and the Coromandel.
        - Vibrations will be intermittent and are at levels unlikely to result in biological responses that negatively impact frogs and their reproduction.

    - Frog populations (both Archey's and Hochstetter's frog) persisted in the vicinity of the historical Golden Cross mine, where similar vibrations from blasts would have been experienced.
- Potential dewatering effects associated with mine dewatering and associated groundwater drawdown – this is unlikely to have measurable effects on frog populations because:
    - Reductions in flow and wetted width are unlikely to negatively impact semi-aquatic Hochstetter's frog habitat quantity or quality (i.e., food resources, refuges, breeding habitat) in lower stream catchments, and would not affect higher order catchments where most of the Hochstetter's frog population occurs.
    - Potential dewatering will have no impact on terrestrial Archey's frogs as their habitat is maintained by surface water, which is not expected to be affected by the mining activities.

Overall, it is considered that measurable adverse effects are unlikely on Leiopelmatid frogs occupying the forests and stream habitats above the Wharekirauponga Underground Mine as a result of vibration and dewatering. However, it is acknowledged that uncertainty surrounding scale and magnitude remains and an assumption of nil risk is not justified based on available evidence. Accordingly, OGNZL has proposed a comprehensive habitat enhancement programme, which includes ~633 ha of pest management, across the project area and surrounds (including areas of high value frog habitat) to address any uncertainty surrounding potential effects on native frogs.

Ongoing monitoring of activities such as blasting, dewatering, and potentially affected biological communities over the life of the mine will help validate the expected project outcomes for frogs.

2 INTRODUCTION

Bioresearches was engaged by OceanaGold (New Zealand) Limited (OGNZL) to assess the ecological effects of the Waihi North Project on native frog populations. The focus of this assessment included the potential impacts of blast vibrations and surface water changes from potential dewatering within the Coromandel Forest Park, related to the proposed Wharekirauponga Underground (WUG) Mine.

Additional potential impacts on native frogs—such as noise, light, air pollution, and biotic factors (e.g., vegetation removal)—have been identified and addressed by other specialist ecologists (Boffa Miskell 2025a; RMA Ecology 2025) and are not covered in this report.

In essence, three ecological consultancies have contributed to the broader project-wide native frog assessment. These include:

> **Boffa Miskell (lead – Katherine Muchna)** – responsible for delivering the overall ecology effects assessment for the WUG component of the Project, which included assessing the potential ecological disturbance effects on fauna (including native frogs) from vegetation clearance activities, artificial lighting, drilling and helicopter noise; continuous noise emissions from the vent raises; and potential biosecurity risks (e.g., introduction of kauri dieback disease) (Boffa Miskell 2025a).
>
> **Bioresearches (Babbage Consultants; lead – Dylan van Winkel)** – responsible for specialist frog advice relating to potential impacts of vibration and dewatering on Archey's and Hochstetter's frogs at Wharekirauponga. Bioresearches also designed and led field surveys for Hochstetter's frog within the project area (this report).
>
> **Lloyd's Ecological Consulting (lead – Dr Brain Lloyd)** – responsible for estimating the proportion of the Coromandel's Archey's frog population in the area affected by potential blast vibrations (Lloyd 2025a) and analysing the results of surveys for Hochstetter's frogs undertaken in 2024 to assess the impacts of stream flow reductions associated with the proposed WUG Mine (Lloyd 2025b).
>
> **RMA Ecology (lead – Dr Graham Ussher)** – responsible for delivering the overarching effects and risk assessment relating to potential effects of the proposed WUG Mine on native frogs (RMA Ecology 2025).

2.1 SUMMARY OF THE PROJECT

The Waihi North Project (WNP) comprises several components, including establishing a new open pit (Gladstone Open Pit), a new underground mine (Wharekirauponga Underground Mine), a 6.5 kilometre decline extending from the planned mine Surface Facilities Area at Willows Road to access the Wharekirauponga Underground Mine, and a tunnel linking the underground to the existing Processing Plant area.

The new Wharekirauponga Underground Mine will be located approximately 11 km north-west of the current Processing Plant under land administered by the Department of Conservation (DOC) (Coromandel Forest Park) (Figure 2.1). Site infrastructure supporting the mine will be located on OGNZL owned farmland located at the end of Willows Road, with only minimal surface features within the forest, in the form of fenced vent raises.

Construction of the access decline and Wharekirauponga Underground Mine will require drilling and blasting to fragment rock into manageable sized fragments for excavation. These activities will result in seismic vibrations that will propagate through the rock mass to the ground surface where populations of Hochstetter's frogs (*Leiopelma hochstetteri*) and Archey's frogs (*Leiopelma archeyi*) are known to occur. The predicted total vibration footprint covers an area of approximately 315 ha. Additionally, hydrological modelling has predicted potential surface water impacts in the form of baseflow reductions in streams within the Wharekirauponga catchment due to dewatering associated with the Wharekirauponga Underground Mine (GHD 2025). Stream flow reductions and associated effects on stream habitat could potentially affect semi-aquatic Hochstetter's frogs that live on the edges of forested streams.

Hochstetter's and Archey's frogs are unique to New Zealand are protected native species and are in decline nationally (Burns *et al.* 2025). Therefore, it is important to determine the type and likelihood of potential effects as a result of the Wharekirauponga Underground Mine on these frogs to ensure adverse impacts are avoided or minimised as far as practicable. Fundamental to determining the extent of potential effects on frogs as a result of the mine, is a good understanding on the biology, ecology, and distribution of these frogs both at the project site and the wider landscape.

2.2 Assessment Approach

To determine the potential effects of blast vibrations and dewatering on native Archey's and Hochstetter's frogs the following approach was taken.

1) **Review of the biology, ecology, and behaviours of Leiopelmatid frogs occurring in the project area.**
    - Literature review of published and grey literature on Leiopelmatid biology and ecology was carried out.
2) **Understand the distribution and abundance of frogs in the Wharekirauponga project area and Coromandel.**
    - Review of historical frog records held in the Department of Conservation (DOC) Bioweb Herpetofauna Database.

- Review of the results of recent surveys and population modelling undertaken by OGNZL as part of the project over the past two years.

3) **Assessment of the effects of vibration on frogs.**
    - Literature review of vibration effects on animals and amphibians.
    - Review of vibration modelling work by Heilig & Partners (2020, 2021) and Lane (2021) for OGNZL.
    - Evidence based assessment of potential vibrations effects on frogs in the project area.
4) **Assessment of the effects of dewatering on frogs.**
    - Literature review of dewatering effects on streams, stream habitat, and amphibians.
    - Review of hydrological modelling reports prepared by GHD (2025) and WWLA (2025c) for OGNZL.
    - Review and analysis of the instream habitat data provided by NIWA (2024) for OGNZL.
    - Evidence based assessment of the dewatering effects on frogs in the project area.
5) **Summary of findings and recommendations for mitigation and monitoring.**

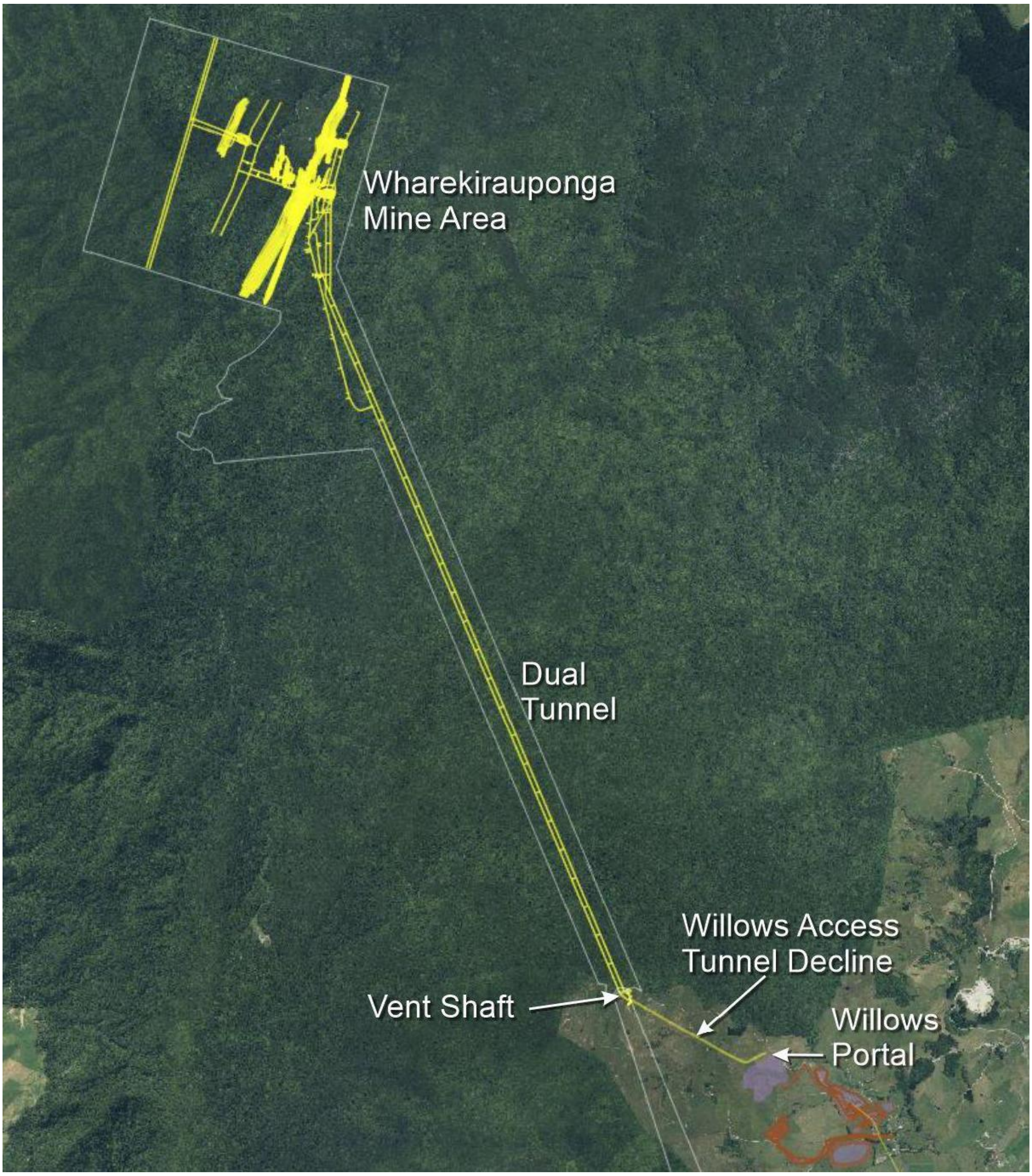

Figure 2.1. Site overview – Location of Willows Access Tunnel Decline and Wharekirauponga Underground Mine. Source: OceanaGold (NZ) Limited.

3 LEIOPELMATID FROG ECOLOGY

3.1 LEIOPELMATID FROGS

Aotearoa/ New Zealand has a small but distinctive endemic amphibian fauna, consisting of three extant species of frogs (Order Anura, Family Leiopelmatidae). All belong to a single genus *Leiopelma* Fitzinger, 1861 and the species include Archey's frog, *Leiopelma archeyi* Turbott, 1942; Hamilton's frog, *Leiopelma hamiltoni* McCulloch, 1919; and Hochstetter's frog, *Leiopelma hochstetteri* Fitzinger, 1861.

The Leiopelmatid frogs represent a unique evolutionary lineage among amphibians and are considered the most archaic frogs in the world (Roelants *et al.* 2007; Ford & Cannatella 1993, Roelants & Bossuyt 2005). They are unique in that they exhibit several plesiomorphic ('ancestral') character traits such as vestigial tail-wagging muscles, cartilaginous inscriptional ribs, the presence of amphicoelous vertebrae, and nine presacral vertebrae (most frogs have eight)[1]. In addition, *Leiopelma* frogs differ from other frogs in that they lack external eardrums (tympanum) and do not have vocal sacs, thus they cannot produce load vocalisations. Rather, it is thought that *Leiopelma* frogs communicate using chemosensory signals (Lee & Waldman 2002; Waldman & Bishop 2004).

All leiopelmatid frogs are carnivorous and eat small invertebrate prey items (Kane 1980; Bell 1995; Eggers 1998; Ziegler 1999; Shaw *et al.* 2012). They are long-lived (e.g. >30 years) and produce small clutches of eggs (not necessarily every year) (Bell 1985, 1994; Bell & Pledger 2010). All species are cryptic and mostly nocturnal, spending the daylight hours under logs or rocks, rarely venturing out during the day. All species also show high site fidelity and have small home ranges (Brown & Tocher 2003; Tocher *et al*. 2006), although broader scale movements have been recorded (Tessier *et al.* 1991; Slaven 1992; Tocher & Pledger 2005).

Leiopelmatid frogs, like most other anurans, have permeable skin that contributes to osmoregulation and electrolyte and fluid homeostasis. Because the skin presents little or no physiological barrier to evaporation per unit surface area, Leiopelmatid frogs need to inhabit saturated or high humidity environments, but behavioural features can also reduce potential evaporative water loss (Cree 1985). During dry periods, Leiopelmatid frogs typically remain on or move to moist substrates in or near humid crevices or refuges. In Archey's frog, the ventral skin absorbs water from the moist or wet substrates, but in Hochstetter's frog the rate of water uptake through the skin is much less, probably because they mostly live in areas where water is constantly available (e.g., streamside retreats) and dehydration is unlikely to occur (Cree 1985). However, some level of fluid absorption through the skin must be possible as Hochstetter's frogs because this species is known to inhabit terrestrial, albeit very humid, environments.

[1] The tailed frogs in the genus *Ascaphus* from North America, are the only other living frogs known to possess these primitive traits.

Leiopelma frog populations have experienced dramatic declines over the past millennium, leading to fragmented and relict distributions. These declines are ongoing, and several biological traits—such as restricted distribution ranges, high longevity, and low reproductive rates (Wells 2007)—contribute to their vulnerability to further population declines and extinction risk. All three species of *Leiopelma* frogs are classified as threatened, both nationally (New Zealand Threat Classification System, Townsend *et al*. 2008; Burns *et al.* 2025) and internationally (IUCN 2018).

Globally, Leiopelma frogs are recognised for their evolutionary distinctiveness and rarity, with all three species included in the top 100 Evolutionarily Distinct and Globally Endangered (EDGE) amphibians. Notably, *Leiopelma archeyi* ranks as the world's most EDGE amphibian species (Zoological Society of London 2008). Consequently, Leiopelmatid frogs hold significant national and global conservation value (Bell 2010).

Two of the three *Leiopelma* frogs (Archey's and Hochstetter's frog) occur in the Wharekirauponga Underground Mine (WUG) project area (Boffa Miskell 2025a; D. van Winkel, pers. obs. 2023). These species differ markedly in their ecology and behaviour and therefore, further detail is provided for each species below.

3.2 ARCHEY'S FROG

Archey's frog (*Leiopelma archeyi*) is a small (≤40 mm snout-urostyle length), terrestrial and nocturnal frog (Figure 3.1). It occurs in small, fragmented populations across the upper North Island and is found in three locations, including Coromandel Peninsula (Coromandel), Whareorino Forest (west of Te Kuiti, Waikato) (Bell *et al.* 1998), and in Pureora Forest (Waikato) where a translocated population is now established (Bishop *et al*. 2013; Cisternas 2018). It occupies dense, damp native forest and ridge tops where humidity is frequently high, from c. 200 to 1,000 m above sea level (a.s.l.). It is not specifically associated with stream, creeks, or other waterbodies. Archey's frog is sympatric[2], and at some locations syntopic[3], with the semi-aquatic Hochstetter's frog (van Winkel *et al.* 2018; Bishop *et al*. 2013).

Archey's frog, like all other *Leiopelma* species, is largely sedentary (Bell 1994; Bell *et al.* 2004; Bell & Pledger 2010, Reilly *et al*. 2015) and employs crypsis and immobility as a primary anti-predator strategy. Indeed, Reilly *et al*. (2015) reported Archey's frog spending 99.86% of their time stationary and none of the Archey's frog they studied exhibited escape behaviour (e.g., jumping or moving away) in response to disturbance stimuli (i.e., an approaching observer). However, at Wharekirauponga, Archey's frog evasion/ escape behaviours (jumping or moving beneath refuges) was recorded in a small proportion (~10–20%) of the frogs that were observed during searches (K. Muchna, pers. comm, March 2022). Archey's frog also employs a sit-and-wait predatory strategy for obtaining food (Bell 1985, Reilly *et al.* 2015).

[2] Occupying the same geographical range.
[3] Joint occurrence of two species in the same habitat at the same time.

Archey's frog is carnivorous and feeds on a variety of small invertebrates, primarily springtails (O. Collembola), mites (Subclass Acari), ants and parasitic wasps (O. Hymenoptera), and land hoppers (O. Amphipoda). The ratio of the largest invertebrate eaten to the frog's snout-urostyle length (SUL) ranged from 0.20 to 0.62 (Eggers 1998). Other invertebrate prey groups include spiders (O. Araneae), flies (O. Diptera), beetles (O. Coleoptera), isopods (O. Isopoda), pseudoscorpions (O. Pseudoscorpiones), hemipterans (O. Hemiptera), and snails (Class Gastropoda) (Eggers 1998; Kane 1980; Shaw *et al*. 2012). Shaw *et al.* (2012) suggested that small collembola were an important prey item for sub-adults, and this is probably true for the smaller juveniles too.

Archey's frog exhibits a specialised mode of reproduction in which there is no free-living tadpole stage, and development occurs entirely within the egg capsule (i.e., there is no free-feeding larval stage). Mating occurs via inguinal amplexus[4] and has been observed in the field during the day in the month of October (Bell 1978). Amplexus was reported among groups of 2–5 frogs in shallow depressions beneath logs where egg clusters were subsequently laid (Bell 1978). The length of time over which amplexus occurs is unknown but considering the nocturnal habits of Archey's frog and the daytime amplexus observations, it is likely that amplexus may extend for up to several hours. Egg laying occurs in spring (November–December) (Bell 1978, 1985). Eggs are unpigmented, about 5 mm in size, and each contain a large yolk. Eggs are laid in clusters (typically 4–15, up to 19 eggs) in dark, damp sites such as under logs and rocks. The male guards (broods) the eggs for a period of 6–9 weeks[5] by sitting high over the eggs with body raised and both fore- and hind-limbs outstretched. The function of egg brooding behaviour in Archey's frog is poorly studied but may represent a strategy to keep the eggs moist (possibly via urinary excretion) (Stephenson 1961). Indeed, male Archey's frogs with eggs or hatchlings store water reserves, presumably for maintaining the necessary hydric environment at the nest site (Bell 1985). Other possible reasons might be to reduce the incidence of fungal or bacterial infection through transfer of chemicals from the adult to eggs, and/ or to protect the eggs from predators. Whatever the function, the males have a strong behavioural predisposition to brood over this period of the lifecycle. Male frogs continue to brood eggs until they hatch and the tiny, tailed froglets then climb onto the back of the male who carries them for up to six weeks while they complete their development (dorsal brooding) (Bell 1978, 1985). Sexual maturity is reached at 3–4 years of age and generation time is approximately 8–10 years. The lifespan of Archey's frog may be more than 35 years.

Archey's frog is currently classified as 'At Risk – Declining' under the New Zealand Threat Classification System (Townsend *et al*. 2008; Rolfe *et al.* 2022; Burns *et al*. 2025), based on a 2024 national population estimate of >100,000 mature individuals and a predicted decline of 10-30% over three generations[6]. It is listed as 'Critically Endangered' (A2ab) on the IUCN Red List (2017, ver. 3.1) based on a dramatic (≥80%) population reduction over 10 years or three generations and a presently stable

[4] Male gripping the female tightly around the groin immediately anterior to the hind legs.
[5] Captive observation.
[6] https://nztcs.org.nz/assessments/169897

population trend (low confidence). Archey's frog is considered the world's most Evolutionarily Distinct and Globally Endangered amphibian species[7,8].

3.3 Hochstetter's frog

Hochstetter's frog (*Leiopelma hochstetteri*) is a small (≤48 mm snout-urostyle length), semi-aquatic or amphibious[9], and nocturnal frog (Bell 1986) (Figure 3.1). It is the most widespread and abundant of all the *Leiopelma* frogs but remains restricted to the North Island. It survives in spatially fragmented populations across the northern half of the North Island (from Northland, south of Whangarei, to Waikato [Maungatautari, Pirongia, Whareorino, and the Coromandel Peninsula], and on East Cape), and on Aotea/ Great Barrier Island (Te Paparahi and Mt Hobson catchments) (Baber *et al*. 2006; Bishop *et al*. 2013). There is substantial genetic variation among the 13 fragmented and isolated sub-populations distributed across the northern half of the North Island. Each of these genetically distinct sub-populations is considered an evolutionary significant unit (ESU) worthy of separate conservation management (Green 1994, Gemmell *et al.* 2003, Fouquet *et al.* 2009; Nájera-Hillman *et al*. 2009b).

Hochstetter's frog is closely associated with streams and typically inhabits a narrow zone along small, forested streams and seeps within native forest fragments. This habitat is usually found in cool, temperate headwater streams (first and second order) in densely forested catchments at elevations between 160 and 800 meters above sea level (Nájera-Hillman *et al*. 2009). The ideal habitat consists of unsilted streams featuring small waterfalls, cascades, and pools (Stephenson & Stephenson 1957; Bell 1978). Frogs are more commonly found in areas with cooler water and air temperatures, as well as higher relative humidity (Nájera-Hillman 2009b).

While they generally avoid large, swiftly flowing waterways, sightings in such habitats have been reported (McLennan 1985; Slaven 1994). Hochstetter's frogs are well-adapted to life on the banks of dynamic streams with fluctuating water levels, tolerating a wide range of water flows—from high-velocity waterfalls to slow-moving seeps and springs. In addition to their adaptability in natural settings, these frogs can survive in highly modified environments, such as farmland or exotic pine plantations (Bell *et al.* 2004)) and have even been observed breeding in silted clay areas (Beauchamp *et al.* 2010; Herbert *et al*. 2014).

They take refuge during the day in damp crevices, under stones, in rock piles or under logs, and in thick leaf litter packs within or immediately adjacent to the water column. Generally, frogs prefer wet substrates under refuges but occasionally some frogs will be entirely or partially submerged in water (Herbert *et al.* 2014). Though, they are occasionally found long distances away from streams in damp

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[7] As assessed by the Evolutionarily Distinct & Globally Endangered (EDGE) amphibian programme formed by the Zoological Society of London.
[8] EDGE species are scored according to the amount of unique evolutionary history it represents (Evolutionary Distinctiveness, or ED), and its conservation status (Global Endangerment, or GE). The scores are then combined to give each species an EDGE score. Those with high ED and GE get the highest EDGE scores and are considered priority species. The conservation status (GE) is based on the IUCN Red List classification.
[9] Amphibious = able to live both on land and in water.

native forest, where they refuge beneath logs, rocks, and dense leaf litter. Hochstetter's and Archey's frogs are occasionally found together under the same terrestrial refuges in damp native forest.

The diet of Hochstetter's frog is poorly known. Frogs emerge at night to forage on small invertebrates encountered along the stream edge and within riparian vegetation (Chapman & Alexander 2006). Hochstetter's frogs are reported feeding on adult terrestrial arthropods, including land hoppers (Order Amphipoda), slater (Order Isopoda), beetles (Order Coleoptera), flies/ sawflies (Order Diptera), mites (Subclass Acari), dragonflies—presumably dragonfly larvae (Order Odonata), and snails (Class Gastropoda) (Kane 1980; Shaw *et al.* 2012; Nájera-Hillman *et al*. 2009a). Other invertebrates such as spiders (Order Araneae), ants (Order Hymenoptera), millipedes (Class Diplopoda), earthworms (Class Clitellata) and slugs (Class Gastropoda) may contribute to the diet of Hochstetter's frog as these are found where frogs shelter (Sharell 1966). Additionally, Stephenson & Stephenson (1957) reported a small, entire fresh-water crayfish in the stomach of one frog, suggesting an aquatic component in the diet of this species.

Hochstetter's frogs require aquatic environments to reproduce. Their reproductive strategy involves laying eggs (up to 22 in number) in shallow depressions with trickling water on the edges of streams. The eggs hatch at a relatively early development stage into larvae with partially developed limbs and well-developed tail fins that enable them to swim, though they are poor swimmers. They do not feed and remain in the shallow water while they develop into small frogs (Bell 1985). So, rely on parental selection of stable pooled water sites.

Hochstetter's frog is currently classified as 'At Risk – Declining' under the New Zealand Threat Classification System (Townsend *et al*. 2008; Rolfe *et al.* 2022; Burns *et al*. 2025), based on a 2024 national population estimate of 20,000–100,000 mature individuals and a predicted decline 10–30% over three generations[10]. It has an IUCN Red List (2015, ver. 3.1) listing of 'Least Concern' (100,000 mature individuals) with an ongoing decreasing (at least 10%) population trajectory. It is ranked no. 38 on the Zoological Society of London's amphibian EDGE list of the most evolutionarily distinct and globally endangered amphibians of the world[11].

[10] https://nztcs.org.nz/assessments/169900

[11] As assessed by the Evolutionarily Distinct & Globally Endangered (EDGE) amphibian programme formed by the Zoological Society of London. EDGE species are scored according to the amount of unique evolutionary history it represents (Evolutionary Distinctiveness, or ED), and its conservation status (Global Endangerment, or GE). The scores are then combined to give each species an EDGE score. Those with high ED and GE get the highest EDGE scores and are considered priority species. The conservation status (GE) is based on the IUCN Red List classification.

Figure 3.1. Hochstetter's frog (*Leiopelma hochstetteri*) (left) and Archey's frog (*Leiopelma archeyi*) (right).

4 DISTRIBUTION AND POPULATION SIZE OF *LEIOPELMA* FROGS IN COROMANDEL AND WHAREKIRAUPONGA AREAS

Understanding the distribution and abundance of Archey's and Hochstetter's frog populations in areas potentially affected by the proposed Wharekirauponga Underground Mine is essential for conducting a thorough impact assessment. Additionally, it is crucial to place these potentially impacted populations in context by comparing them with others across the species' range (i.e., within the Wharekirauponga catchment and Coromandel Forest Park).

To assess this, historical records from the DOC Bioweb Herpetofauna Database (accessed 2022) were initially reviewed to determine the distribution of Leiopelmatid frogs in the project area and the wider Coromandel region. The results of recent frog surveys conducted by Boffa Miskell and OGNZL, along with detailed analyses by Lloyd (2025a, 2025b), were also evaluated. A summary of the findings is presented below.

4.1 ARCHEY'S FROG

In the Coromandel, there are three naturally occurring sub-populations of Archey's frog, inhabiting approximately 52,000 hectares of native forest above 200 m a.s.l. along the region's main axial mountain range (Figure 4.1). These sub-populations are generally referred to as the 'Moehau,' 'Middle,' and 'Southern' sub-populations (Lloyd 2025a). A notable gap exists between the 'Middle' and 'Southern' sub-populations, likely a result of historical land-use practices such as logging and agricultural clearance. Data indicate that Archey's frog densities are highest in undisturbed, old-growth mixed podocarp-hardwood forests at mid to high altitudes (>400 m a.s.l.) (DOC Bioweb Herpetofauna Database, accessed 2022; Lloyd 2025a).

To improve the understanding of Archey's frog distribution in the Wharekirauponga and wider Coromandel areas, surveys were undertaken by OGNZL over the period of 2018 to 2022 (OGNZL un pub. data). Records obtained from these surveys were pooled with historical records extracted from the DOC database (i.e., 324 valid records between 1970 and 2017), and habitat preference information (altitude, habitat quality/ vegetation type) was used to describe the distribution of Archey's frogs in the Coromandel (Lloyd 2025a).

Approximately 315 hectares of land, ranging from 90 to 330 m a.s.l., in the Wharekirauponga catchment is expected to be affected by vibrations originating from proposed mine blasting activities. Half of this area consists of regenerating forest—a consequence of historical disturbance—resulting in lower-quality habitat for Archey's frog compared to other parts of its range. The 315 ha vibration footprint represents approximately 2.23% of Archey's frog's southern Coromandel distribution, 0.66% of the combined southern and middle Coromandel ranges, 0.61% of the species' inferred 52,000 ha distribution in the Coromandel, and 0.60% of its current natural range in New Zealand (excluding the translocated population at Pureora) (Lloyd 2025a).

Given that the regenerating habitat within the vibration footprint likely supports lower-density populations of Archey's frog compared to other areas, it is estimated that no more than 0.61% of the entire Coromandel population, and significantly less than 0.61% of the national population, resides in this footprint.

Lloyd (2025a) went further to estimate Archey's frog density and population size in the Wharekirauponga Underground Mine footprint using nocturnal plot surveys data from Boffa Miskell surveys in Wharekirauponga (Boffa Miskell 2016, 2018, 2019, 2021) and the results of a capture-recapture study investigating the effect of past vegetation disturbance on abundance of Archey's frogs (Hotham 2019). Using this information, Lloyd (2025a) estimated the number of adult Archey's frogs living in the predicted vibration footprint of the proposed mine ranged between 48,888 and 152,774 (61,406–278,785 for all age frogs) (Lloyd 2025a). This study also suggested that the frog habitat inside the Wharekirauponga study area was relatively low quality for Archey's frogs compared to many other areas in Coromandel and that the frog population within the predicted vibration footprint contributed <1% of the total Coromandel population (Lloyd 2025a).

4.2 HOCHSTETTER'S FROG

Hochstetter's frog is widely distributed and abundant across the Coromandel Peninsula (Figure 4.1). However, prior to 2019, there was limited information on the presence and abundance of Hochstetter's frogs in the Wharekirauponga catchment. Baseline surveys by Boffa Miskell in 2019 and 2020, and a survey in 2024 have added to the information. These surveys and results are briefly described below.

4.2.1 Boffa Miskell investigations 2019-2020

Boffa Miskell undertook baseline monitoring assessments (broad-scale biodiversity inventory) over approximately 200 ha of the Wharekirauponga catchment in the Coromandel Forest Park in 2019 and 2020. Surveys were undertaken across pre-selected sites and assessed terrestrial fauna, vegetation communities, and freshwater environments (Boffa Miskell 2019, 2020). As part of these assessments, Hochstetter's frogs were manually surveyed for along stream margins during the day (between 1200 and 1700 hrs). Rocks, crevices, and other debris were lifted and inspected for frogs. In addition, their freshwater team also undertook Hochstetter's frog surveys during their stream assessment work. Once a frog was found it was photographed in situ and its location marked with a GPS.

In 2019, seven Hochstetter's frogs were found across five streams or tributaries including some larger streams in the catchment: Teawaotemutu, Wharekirauponga and Adams Stream, and some smaller streams such as tributaries to Thompson Stream (Boffa Miskell 2019). In 2020, nine Hochstetter's frogs were found across several smaller tributaries to the larger streams in the catchment and sites surveyed included some that were surveyed in 2019, and other previously un-surveyed tributaries along the Golden Cross Track (Boffa Miskell 2020).

Both surveys identified Hochstetter's frogs of a variety of ages, reflecting a stable population with adequate recruitment in the streams surveyed. Hochstetter's frogs were common in smaller rocky tributaries, including in high-activity areas associated with exploration drilling, and the frogs were also found in some streams and tributaries within the Wharekirauponga catchment. The surveys did not however, detect Hochstetter's frogs in the larger fast flowing streams (Boffa Miskell 2020).

4.2.2 Hochstetter's frog distribution and abundance inside versus outside the potentially affected Wharekirauponga catchment.

Prior to 2023, Hochstetter's frogs were known from scattered records in the Wharekirauponga catchment and historical observations in the surrounding landscape, particularly near the Golden Cross Mine site, approximately 3.5 km southwest of the proposed Wharekirauponga Underground Mine.

In January 2024, a dedicated survey was conducted to enhance the understanding of Hochstetter's frog populations both within and outside of the catchments potentially impacted by the proposed Wharekirauponga Underground Mine. The study aimed to identify any differences in frog distribution and abundance between these areas. To ensure the reliability of the results, a biostatistician was involved in designing the study and analysing the data. A summary of the study design and results are provided below.

4.2.2.1 Hochstetter's frog survey methods

To investigate frog distribution two broad treatment areas were chosen. These included:

1) Affected area – extending along 12.1 km of stream length in the lower reaches of Edmonds Stream sub-catchment (Figure 4.2), and
2) Unaffected ('control') area – extending along 42.1 km of stream length spread among three stream sub-catchments (Edmonds, Marototo, and Waiharakeke) (Figure 4.2).

In each treatment area, 40 randomly selected 20 m lengths of stream were chosen to be searched for Hochstetter's frogs (Figure 4.2). Sites were randomly selected to avoid bias in the survey results, and a range of explanatory variables, such as elevation, vegetation type, and substrate, were included in the analysis to help explain any variations observed between the two areas. The process for selecting the transects is described below.

4.2.2.1.1 Frog survey transect selection

A desktop GIS exercise was conducted to map existing stream alignments and randomly select 80 frog survey transects. This included 40 transects inside the area potentially affected by the Wharekirauponga Underground Mine (e.g., areas subject to potential dewatering effects) and 40 outside the affected area (i.e., areas not exposed to potential dewatering effects). This involved:

1) Importing the drainage layers extracted from the Land Information New Zealand ("LINZ") Data Service into QGIS (ver. 3.34.3.) GIS software.

2) Overlaying the drainage layers provided by Flo Solutions, which refined the LINZ stream alignments.
3) Overlaying 1 m LiDAR contours and converted to a hill shade plot to visualise topography at high resolution. Then added predicted stream alignments based on the hill shading topography.
4) Overlaying the sub-catchment boundaries supplied by OGNZL (Waiharakeke, Thompson, Edmonds, T-Stream East, T-Steam West, Wentworth, Wharekirauponga Main, and Wharekirauponga2).
5) Determining the extent of the potentially affected area, by overlaying the groundwater drawdown and depth to water contours supplied by OGNZL and demarcating the outside boundary where depth to groundwater was <10 m and groundwater drawdown effects may potentially be expected.
6) Dividing the entire lengths of the stream alignments within the potentially affected area into 20 m lengths, each of which were assigned a unique number.
7) Using a random selection function in QGIS to identify transects where frog surveys were to be carried out. Transect selection included:
    a. 40 randomly selected transects (i.e., 20 m long stream length transect) inside the affected areas of Edmonds sub-catchment (i.e., transects where surface ground water was <10 m below the surface and groundwater drawdown is predicted), and
    b. 40 randomly selected transects outside the affected areas, including 10 transects within the Edmonds sub-catchment and 30 transects in the Golden Cross catchment.

4.2.2.1.2 Frog search methodology

1) Two searchers were assigned to each transect.
2) A tape was used to demarcate the 20 m transect.
3) One searcher began searching the transect, moving upstream from 0 m to 10 m, while the other searched from 11 m to 20 m.
4) Searchers move slowly upstream looking for frogs beneath rocks, debris, in rock crevices, in leaf litter packs, and debris dams. Headlamps were used to increase visibility and frog detection.
5) When a frog was encountered
    a. Time of observation was noted;
    b. The frog’s position along the tape (measured to the nearest 10 mm) was recorded;
    c. The size of the frog was recorded by hovering a ruler over the frog and measuring snout-urostyle length (i.e., tip of snout to base of hind limbs/ tip of ischium), to the nearest 5 mm. Frogs were not touched or disturbed. Measurements were used to assign age classes: juvenile, sub-adult, and adult frogs (Table 4.1);
    d. Where SULs could not be accurately measured (e.g., where frogs were in deep crevices or jumped away prior to measurement), estimated SULs were recorded (these measurements to be excluded from SUL analyses, but included in age class category/ occupancy estimates); and

   e. Microhabitat type was recorded (e.g., under rock, under/within log, under/within vegetation/twigs/roots, within crevice, open habitat).

6) Search time along each 10 m section of the transect was recorded by each person, to give a total search time for the entire 20 m transect length.
7) The intention was for each 20 m transect to be searched three times (i.e., (40+40)*3 = 240 transect searches).

Table 4.1. Hochstetter's frog age class classifications

Age class	Age (years)	Snout-urostyle length (SUL)
Juvenile	0–1	>18 mm
Sub-adult	1–2	18–24 mm
Adult	2+	25–39 mm
Mature adult female		<39 mm

4.2.2.2 *Stream characterisation & covariates*

Habitat variables (both broad- and micro-scale) were collected to determine the influence (if any) of 'site' effect' (i.e., is frog presence related to specific habitat types, or stream characteristics).

Several environmental variables were recorded during the transect searches and the characteristics of the stream along the 20 m length were documented by recording:

- General weather conditions (e.g., cloud cover, rainfall, wind, etc.).
- Air temperature at the start of the survey
- Relative humidity at the start of the survey
- Water temperature at the start of the survey
- Stream (wetted) width every 2 m along the length of each transect.
- Water depth every 2 m along the length of each transect. For wide streams, a series of depth measurements along width of the stream were taken (e.g., measurement every 200 mm).
- Substrate type every 2 m along the length of each transect.
- Canopy cover – average cover (percentage) along each 10 m transect length.
- Searcher name for each 10 m transect length.
- Start time and end time for each 10 m transect.
- Search date
- Number of refuges searched (using handheld counters).
- Transect elevation.
- Water velocity.
- Representative photographs of the 10 m lengths.

4.3 Results of frog distribution and abundance surveys

The results are described in detail in Lloyd (2025b) but are briefly summarised below.

Six of the selected transects could not be surveyed due to access and safety concerns and were replaced by transects at nearby locations. In the Edmonds Affected Area 37 of 40 transects were surveyed three times, and three transects were surveyed four times. Only 12 of 40 transects outside the affected area were surveyed, most (n = 10) transects occurring along the Marototo Stream. Three of the 12 transects were surveyed twice, eight were surveyed three times and one was surveyed four times.

There were differences in elevation, vegetation type, and stream widths between the two treatment areas, making it difficult to directly compared the two treatment areas.

4.3.1.1 Frog distribution, relative abundance, and demographics

- Hochstetter's frogs were found along 16 of 40 transects (40%) in the affected area and eight of 12 transects (67%) outside the affected area.
- Frog encounter rates were significantly ($p<0.001$) lower along transects in the affected area (0.228 frogs/ survey; CI95%: 0.151–0.329) compared to outside the affected area (1.088 frogs/ survey; CI95%: 0.766–1.5).
- The distributions among size classes of frogs found in the two areas were significantly ($p<0.05$) different, with a lower proportion of juvenile frogs (11% vs. 30%) and a higher proportion of mature females (21% vs. 0%) found in the affected area.
- Abundance estimates outside of the affected area (2.9 and 3.1 frogs/ transect) were considerable higher than estimates from in the affected area (0.91 and 1.05 frogs/ transect).
- Detection probabilities were also higher outside the affected area (0.36 compared to 0.25 and 0.26). Difference in estimates from the two areas stem from the much higher numbers of frogs (n = 11) found during surveys of two high elevation (≥400 m) transects. By comparison, all transects in the affected area were <340 m a.s.l.
- Extrapolating abundance estimates for the forty 20 m-long transects in Edmonds Affected Area to the 12.1 km of streams in the area's sampling frame, provides estimates of the total Hochstetter's frog population in the area of 549 (CI95%: 238 – 1,270) and 637 (CI95%: 271 – 1,597) from classical and Bayesian analyses respectively. Estimates of the total Hochstetter's frog population in the sampling frame outside of the affected area by extrapolating from transect abundance estimates were not attempted because of the small, unrepresentative sample of transects.

4.3.1.2 Stream and habitat characteristics

- Streams outside the affected area were generally wider (i.e., greater wetted width; mean = 2.13 m, *n* = 12), compared to streams in the affected area (mean = 1.85 m, *n* = 40). However, on transects where frogs were found, stream wetted width was significantly ($p<0.05$) greater in the affected area (mean = 2.6 m) compared to outside the affected area (mean = 1.3 m).

Hochstetter's frogs are usually found and are more abundant in narrower headwater streams (Herbert *et al*. 2014) and this was true for transects outside the affected area but not in the affected area. In affected area mean stream wetted width at capture sites was 2.6 m compared to 1.9 m along the 40 transects. Outside the affected area mean width at capture-sites was 1.3 m compared to 2.1 m along all 12 transects.

- A higher proportion of frogs were found in leaf packs (29% *vs.* 11%) and under wood or logs (7% *vs.* 0%) and a lower proportion under rocks (57% *vs.* 78%) in the affected area compared to outside the affected area.
- Inside the affected area, frogs were found more associated with cobble substrate compared to the proportion of cobble substrate available along transects.
- Outside the affected areas, frogs were found more associated with vegetation and less with bedrock compared to what was available (i.e., proportions of habitat along the transects).
- Inside the affected area, the best model showed that frog counts increased with stream wetted width, mean survey duration, and mean number of refuges, but declined as a result of interaction between mean duration and mean number of refuges.
- Outside the affected area, frog counts increased with the increasing total number of refuges searched and total search duration. Frog counts were highest in the mid-elevation class (≥400–<500 m a.s.l.), lowest in the low elevation class (<400 m a.s.l), and intermediate in the highest elevation class (≥500–<700 m a.s.l.).

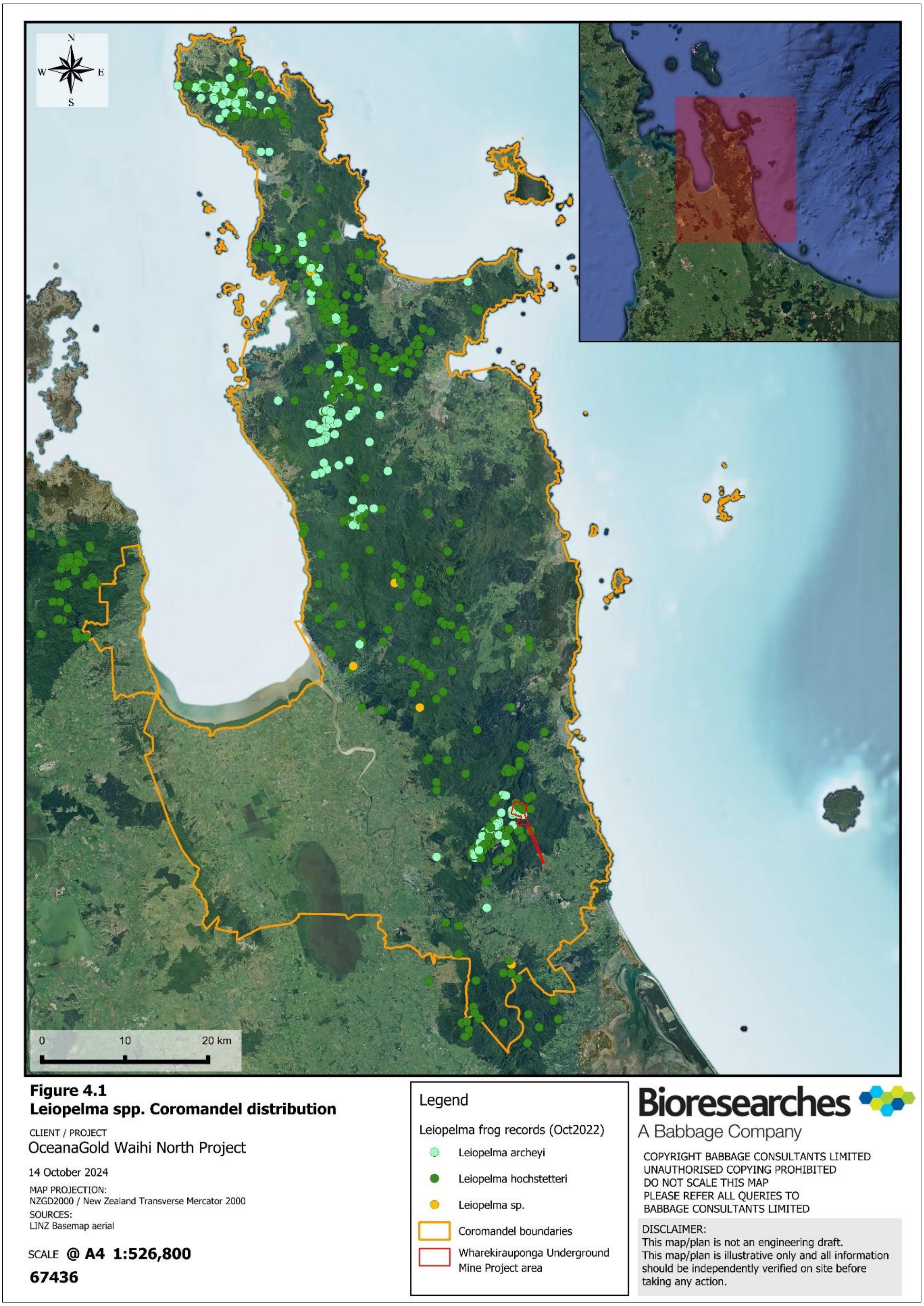

Figure 4.1. Distribution maps of Archey's and Hochstetter's frogs in the Coromandel. Records sourced from DOC Bioweb Herpetofauna Database (accessed 2023).

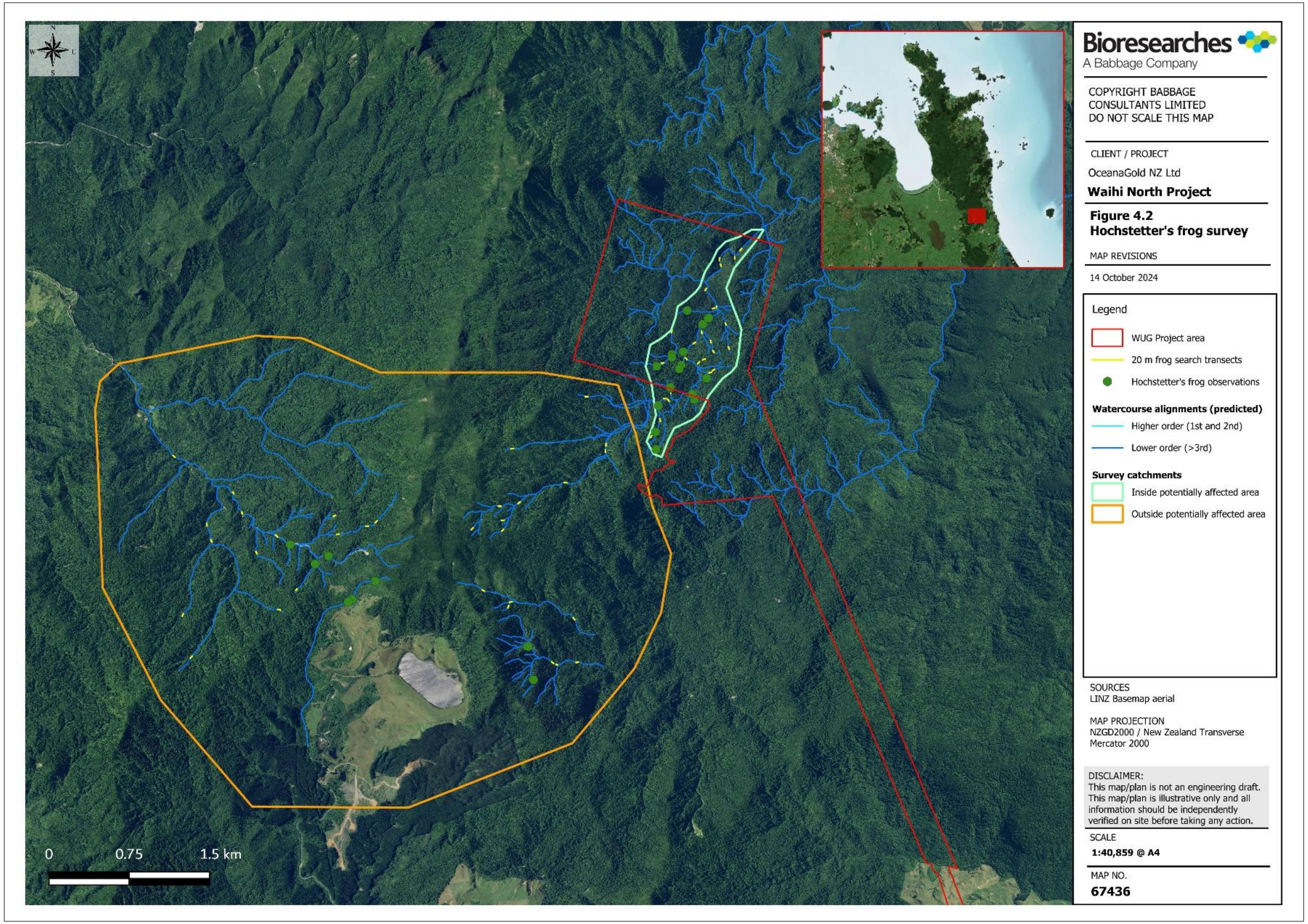

Figure 4.2. Hochstetter's frog transect survey locations, inside and outside the potentially affected stream catchments.

5 VIBRATION EFFECTS ON NATIVE FROGS

Vibration pulses associated with blasting are anticipated as part of the Wharekirauponga Underground Mine activities. Blasting to fragment rock into manageable size fragments generates a great quantity of energy, which in turn creates a vibration pulse that propagates through the rock mass to the ground surface. As the vibrational pulse travels outward from the source, it diminishes or attenuates. With increasing distance, the affected area greatly increases, but the energy becomes widely dispersed.

OceanaGold (NZ) Limited's approach to blasting is to conservatively design blasts to lower levels of vibration, to ensure permitted and consented vibration limits are not exceeded (Heilig & Partners 2022). Nevertheless, blasting may generate perceptible levels of vibration at the surface, including over areas occupied by native frogs. The following assessment determines the likelihood of vibration impacts on these frog populations.

5.1 VIBRATION FOOTPRINT OF THE WHAREKIRAUPONGA UNDERGROUND MINE

The current mine design would see intermittent surface vibrations ≥2 mm/s from underground blasting extending over an area of approximately 315 ha of Coromandel Forest Park (comprising 302.6 ha in the Wharekirauponga catchment and 12.3 ha in the nearby Waiharakeke catchment (Figures 5.1–5.3) (Lloyd 20225a)). Forest areas above the proposed Wharekirauponga Underground Mine and access shaft will be affected by vibrations according to the distribution and frequency shown in Figure 5.1 over an approximately 14 year period. The maximum area affected by vibrations of ≥2 mm/s is expected to reach 282 hectares in Year 10 of the operation. Higher vibration levels will affect smaller areas for shorter durations, with only 3.3% of the total area experiencing vibration levels ≥15 mm/s (Figures 5.2 & 5.3)[12]. Most blast vibrations will be below the maximum values indicated by the contour, and vibration events will be transient—the peak particle velocity lasting only seconds and the total vibration lasting less than 10 seconds—and will occur intermittently, with 7 to 15 blasts expected per week (Lane 2021; Lloyd 2025b).

Blasting associated with the development of the Access Decline (i.e. the tunnel required to access the orebody originating in Willows Road Farm, Years 1–4) will not produce vibration levels >2 mm/s north of Willows Road Farm (i.e. under Coromandel Forest Park) (Heilig & Partners 2022).

[12] For comparison, vehicle traffic along a residential road can generate 1-2 mm/s at 3–6 metres away (Henwood & Haramy 2001), a logging truck between 5–10 mm/s, and a train more than 20mm/s near the tracks and several mm/s at 10 or so metres away (Heilig & Partners, unpub. data).

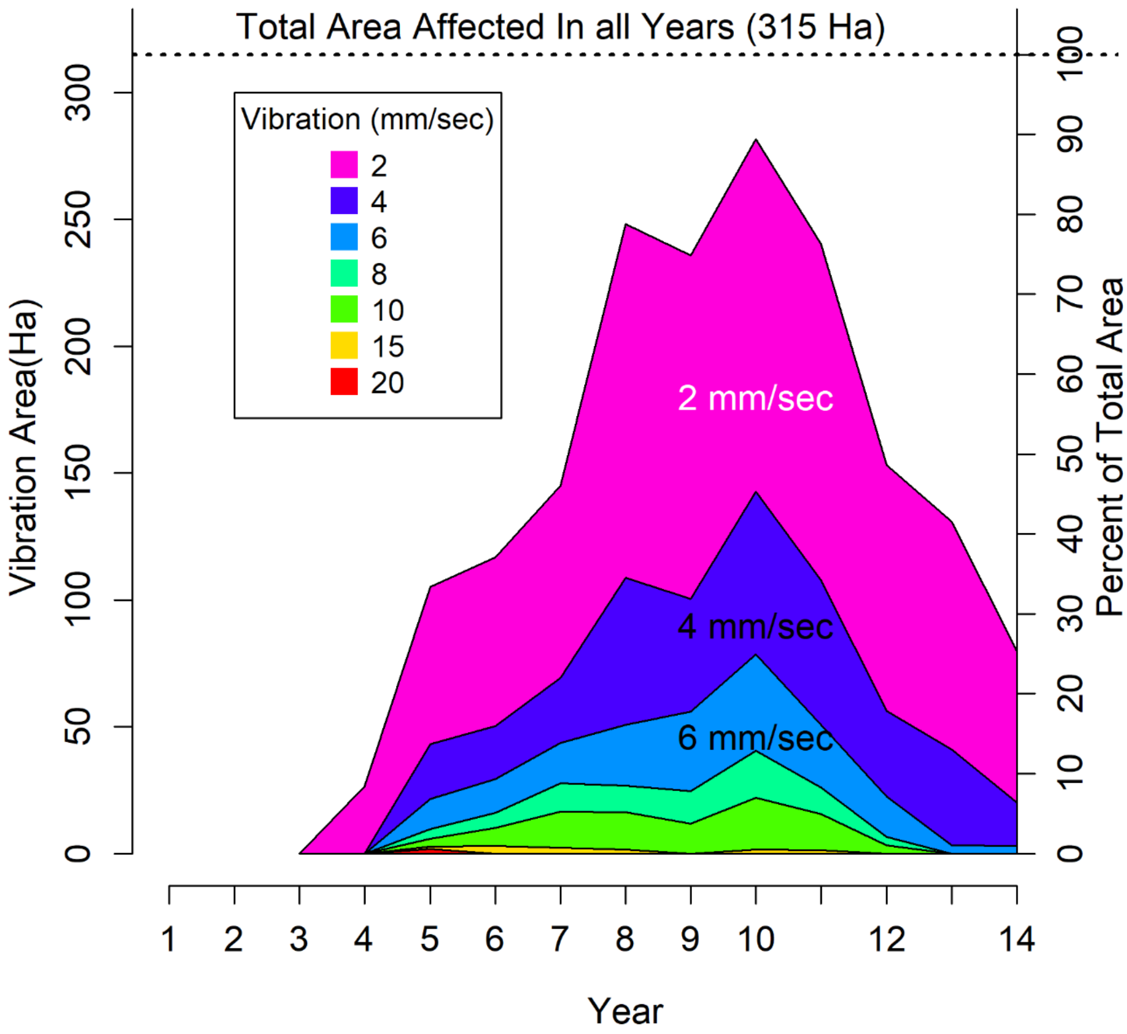

Figure 5.1. Predicted changes in the extent of areas affected by different vibration intensity levels, Years 0 to 14, for the current mine design (figure sourced from Lloyd 2025a). The period over which mining-related surface vibrations >2mm/ s occur is from Year 4 to Year 14 (10 years).

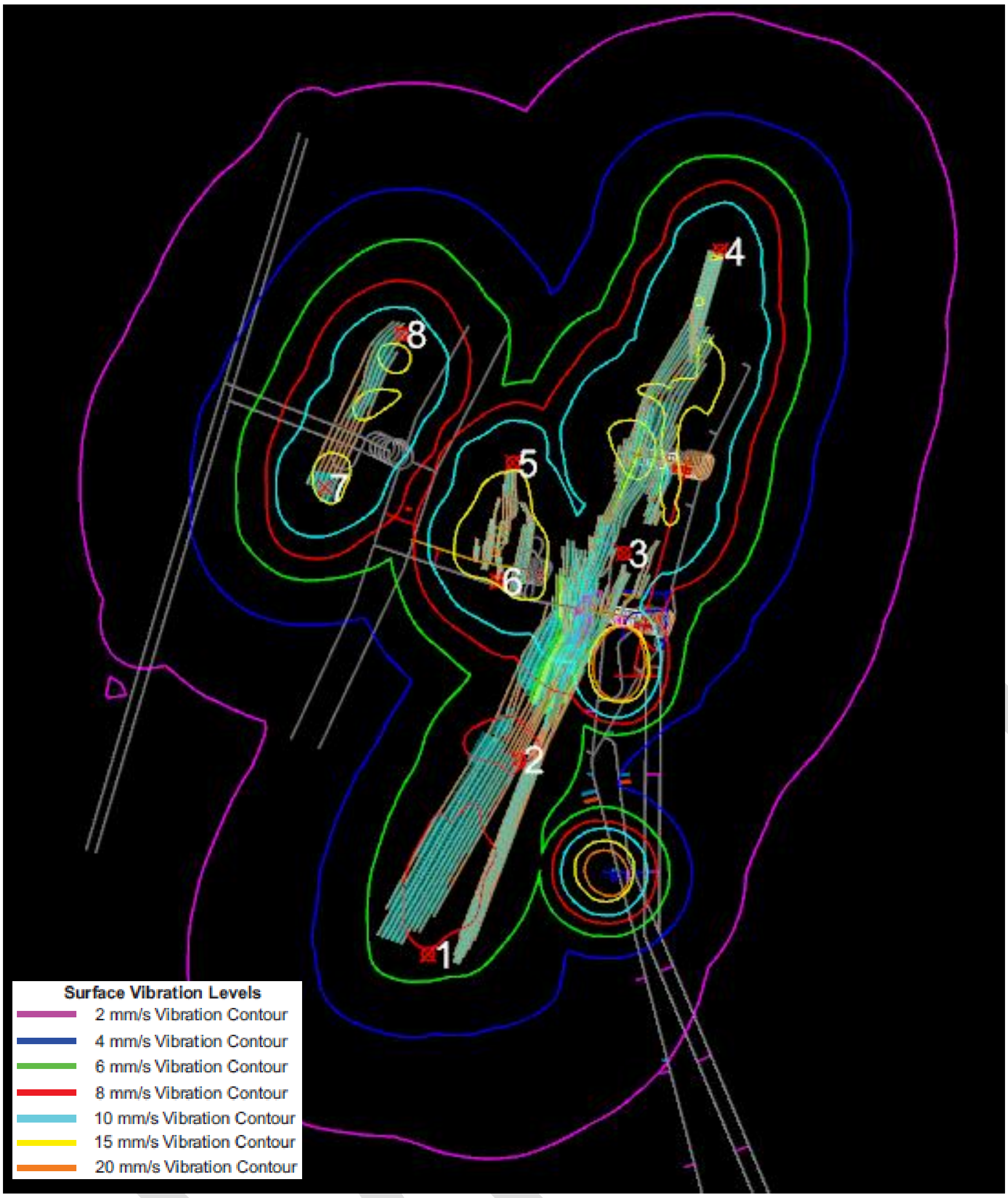

Figure 5.2. The extent of the predicted vibration footprint of the proposed Wharekirauponga Underground Mine for the current mine design. Contours of the vibration levels delineate the maximum extents of seven vibration intensity levels. Figure sourced from Heilig & Partners.

Figure 5.3. Modelled vibration levels and associated vibration contours from blasting at the proposed Wharekirauponga Underground Mine for the current mine design. Contours of the vibration levels delineate the maximum extents of seven vibration intensity levels. Blast histograms for the six sites with the highest vibration experience also shown. Figure adapted from Plates developed by Heilig & Partners (see Lane 2021).

5.2 Seismic (vibration) detection by animals

Many animals are sensitive to substrate-borne vibrations and vibration detection is an important sense that is used for intra- and interspecific interactions in diverse animal taxa (Takanashi *et al.* 2016). While a growing body of evidence suggests that anthropogenic substrate vibrations (as opposed to anthropogenic noise) could be sources of mechanical disturbance to animals, the field remains under-researched, and the effects on many animal groups are still poorly understood.

Vibration is a form of energy that travels in waves that can be physically felt. These waves are oscillatory in nature and have both an amplitude and frequency. The amplitude contributes to the intensity of the vibration and is represented by how far the peak of the wave moves past the position of equilibrium. Frequency is the amount of time that it takes to complete one cycle from a point on one wave to the same point on the next wave (measured in Hertz). The magnitude of vibration can be measured in relation to the amplitude by displacement from the point of equilibrium (often measured in millimetres), the velocity of wave movement (quantified in mm/s) or acceleration past the neutral point measured in meters per second squared (mm/s^2) (Reynolds *et al.* 2018).

Different species perceive vibration to a lesser or greater degree depending on the frequency (Hz) of the vibration. For example, Norton *et al*. (2011) demonstrated that small rodents (rats and mice) are more likely to be affected by vibration in frequency ranges generated by a vibration source as compared with humans. This also highlights that the degree of perception is dependent on the size of an animal. In addition to the frequency of vibration, other factors that will determine the effects on animals include magnitude, duration, whether the vibration is directed at the whole body or is localized, and potentially individual variation in perception across species or within the same species.

Amphibians are highly sensitive to air-borne sound and among terrestrial vertebrates, are the most sensitive to vibrations (Caorsi *et al.* 2019). Typically, the tympanic middle ear and inner ear structures of anurans function to detect airborne sound by transferring sound energy to fluid vibrations sensed by hair cells in the inner ear (Pereyra *et al.* 2016). These structures, and specifically those associated with the inner ear (i.e., three organs: the amphibian papilla, the basilar papilla and the sacculus; Caorsi *et al*. 2019), are also responsible for sensing seismic (vibration) signals (Narins & Lewis 1985; Christensen-Dalsgaard & Narins 1993; Christensen-Dalsgaard & Jørgensen 1996). The pathway for substrate vibration sensing occurs via the operculum, a cartilaginous disc that is in physical contact within in the oval window of the inner ear in amphibians (i.e., their movement is coupled), which transfers substrate vibrations to the inner ear organs. In amphibians, the saccule remains sensitive to low-frequency seismic vibration due to the relative movement between the sensory epithelia and otoconia caused by traveling waves in the substrate (Han & Carr 2024 and references within).

Because the inner ear structures are responsible for sensing vibration signals, it is not essential that the structures of the middle ear are present. Indeed, studies on ‘earless’ amphibian species (species lacking a middle ear) demonstrate sufficient ability to sense vibration and some groups (e.g., bufonids) show vibrational sensitivities equivalent to ‘eared’ species (Womack *et al.* 2017 and references within).

It has been postulated that the loss of the middle ear could allow freer movement of the operculum, increasing sensitivity to substrate vibrations in 'earless' species (Gridi-Papp & Narins 2010).

Furthermore, species-specific extratympanic pathways, including lung pathway, opercularis pathway, and/ or bone pathways (e.g., skull conduction enhanced by resonation of the oral cavity, lowering head to contact floor, or transmitted to the inner ear fluid directly by the skeletal system along the entire spine) may also be utilised to sense vibration in 'earless' species (Gridi-Papp & Narins 2010; Pereyra *et al.* 2016). Such substrate vibrations that travel through the ground or plants have been suggested as important communication mechanisms for some 'earless' species (Womack *et al.* 2017).

It is important to note that the above observations are general in nature, and there appear to be no studies that explore if and how leiopelmatid frogs (including Archey's and Hochstetter's frogs) perceive vibrations, including those that are not associated with noise.

5.3 EFFECTS OF VIBRATION ON ANIMAL BEHAVIOUR

There is a growing body of evidence on behavioural and physiological responses to vibration stimuli in animals (e.g., rodents – Reynolds *et al*. 2018; poultry – Scott 1994; bats – Snyder *et al.* 2015; frogs – Felt *et al.* 2012; Márquez *et al*. 2016; and Caorsi *et al.* 2017, 2019; and lizards – Han & Carr 2024). Studies on rodents have demonstrated that vibration can cause alterations in reproduction as well as mortality and morbidity in other laboratory species, including frogs (Garner *et al.* 2018). Nevertheless, while anthropogenic substrate vibrations could be sources of mechanical disturbance for animals, including frogs, that disrupt behaviour this field is still in its infancy is poorly understood (Caorsi *et al.* 2019).

With respect to amphibians, while there have been studies examining the impacts of noise (e.g., traffic noise) on behaviour, very few studies have investigated vibration effects. Amphibian response to vibrations is most readily demonstrated in calling or vocalising species, by reduced male calling rates in response to anthropogenic seismic activity (Gridi-Papp & Narins 2010; Mazerolle *et al.* 2015; Caorsi *et al.* 2019). For example, the call frequency reduces or ceases in response to an observer walking at a few meters distance, but not in response to observer-emitted vocalisations (Gridi-Papp & Narins 2010). Caorsi *et al.* (2017, 2019) investigated the effects of seismic sources associated with traffic and wind turbines on frogs and demonstrated a significant reduction in call rate by males and a clear negative effect of anthropogenic vibrations on anuran communication. However, such effects are not relevant for amphibians that do not call or vocalise (e.g., leiopelmatids). Other studies looking at anuran responses to vibration, include stimulated emergence behaviour (Márquez *et al.* 2016), flight/ movement response (Mazerolle *et al.* 2015), and spontaneous or early hatching of eggs (Warkentin 1995). Another study reported rainfall-induced vibrations in soil are the cues that trigger the emergence of arid-zone toads from underground (Márquez *et al.* 2016).

It is not only physical behaviour that is affected by vibration, as vibration can elicit stress-mediated effects such as increases in heart rate (Reynolds *et al.* 2018) and physiological changes (Felt *et al.* 2012). Over time, episodic or sustained vibration could potentially lead to adverse impacts on individuals.

One study demonstrated morbidity and mortality in obligate aquatic African clawed toads in the laboratory in response to nearby high intensity, persistent construction vibration[13], which caused observable vibrations in the water column (Felt *et al.* 2012).

Understanding how vibration influences behaviour is complicated by the interplay between characteristics of vibration, including amplitude, duration and return period (the length of time a vibration is sensed until returning to normal state), and 'frequency' of vibration events[14] (how often vibrations occur). All characteristics need to be considered to completely understand the effects on animals.

Amplitude is the characteristic that describes the severity or intensity of a vibration. Animals may respond in different ways to vibrations depending on the amplitude. In instances where the amplitude is low, animals may not respond at all but where amplitude is high (very intense) and acute or sudden, animals may react with a startle response. A startle response is a largely unconscious defensive response to sudden or threatening stimuli and typically involves abrupt cessation of ongoing movements, such as freezing or thanatosis (long-lasting freezing) or a fast jerky movement with short latency (e.g., jumping, moving away rapidly). In most instances, a startle response is short-lived, and the animal successfully recovers and continues with more controlled and decisive actions. However, where individuals are engaged in important biological behaviours (e.g., feeding, mate attraction, mating, egg brooding), startle responses, especially movement away from the engaged behaviour, may be temporarily disruptive. It could also cause stress response (energy demands) and potentially lead to long-term individual fitness effects if mating or recruitment is affected (e.g., mate desertion, abandonment of eggs, premature hatching). There is paucity of research on startle effects resulting from vibration stimuli yet Götz and Janik (2011) reported that repeated startling by anthropogenic noise sources might have severe effects on long-term behaviour and potentially and reduced individual fitness or reduced longevity of individuals. Since noise and vibration are sensed by the same organs in the body, it is plausible that similar effects could result from repeated startling in response to vibration stimulus.

Alongside amplitude effects, the duration of vibration (length of time a vibration is sensed until returning to normal state) and how often vibration occurs are likely to influence animal behaviour. Intermittent vibration is thought to produce more adverse effects than continuous vibration due to its unpredictability (Carman *et al.* 2007). On the other hand, animals have been shown to adapt to avoid fitness-relevant physiological costs in response to sustained stimuli (e.g., noise-legacy populations of wood frogs have adapted to physiologically costly anthropogenic [traffic] noise; Tennessen *et al.* 2018). Similarly, Garner *et al.* (2018) suggested that rodent responses (e.g., startle and freeze reflexes) seemed to decrease when repeatedly exposed to vibration, though their results were largely inconclusive.

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[13] Jack hammer that was being used in an adjacent room approximately 10 ft (~3 m) away.

[14] Not to be confused with "frequency" i.e., the amount of time that it takes to complete one cycle from a point on one wave to the same point on the next wave. The term "Hertz" is used as a unit of measure for frequency and is the number of cycles per second.

Vibration impacts on animals appear to be influenced by a combination of amplitude, duration, and frequency of vibration events, as well as body size characteristics, species ecology, and individual variation in perception across species or within the same species. Consequently, it is exceedingly difficult to determine if and how a species will respond to vibration stimuli and even more difficult to determine what the short- and longer-term affects might be without designed laboratory experiments or intensive monitoring of wild populations pre- and post-stimulus.

5.4 VIBRATION SENSING IN *LEIOPELMA* FROGS

Leiopelmatid frogs possess primitive traits that set them apart from all other frog species. These include the absence of several anatomical features commonly found in other frogs, along with some additional unique characteristics, such as cartilaginous inscriptional ribs and extra presacral vertebrae. Notably, leiopelmatid frogs lack middle ear structures, such as tympanic membranes (a round patch, corresponding to an eardrum, found behind and below the eye in many frogs) and columella. The operculum and inner ear structures remain present (Stephenson 1951; Pereyra *et al.* 2016). Leiopelmatid frogs also lack eustachian tubes and vocal sacs (Stephenson 1961; Bell 2010). As a result, *Leiopelma* are incapable of hearing sound in the traditional sense and vocalisations are very limited compared to most frogs, which typically produce and respond to loud calls during the mating season. The absence of anatomical structures for communication suggests that chemosensory signals might be important in leiopelmatid frog communication; possibly like communication in salamanders where chemosignals are used to recognise the size and individuality of their conspecifics. Furthermore, seismic (vibration) signals may play an important role in communication or behavioural response, as this is seen in other 'earless' anurans (e.g., bufonids; Womack *et al.* 2017).

A small body of research has demonstrated that chemosensory cues play an important role in conspecific communication among *Leiopelma* frogs (Lee & Waldman 2002; Waldman & Bishop 2004). However, communication via other means, such as vibratory modalities, has not been investigated—there is no published literature on vibration sensing in *Leiopelma* (Waldman & Bishop 2004). Additionally, we have been unable to find any research on vibration perception in their closest relatives, the two species of *Ascaphus* frogs from North America. This gap in knowledge makes it difficult to determine the extent to which *Leiopelma* can detect vibrations and whether anthropogenic vibrations might affect them. We also cannot rule out the possibility that seismic (vibratory) signals could play a significant role in their communication or behavioural responses, as has been observed in other 'earless' anurans (Womack *et al.* 2017).

The ecology of leiopelmatids may provide some insights into the importance of vibration sensitivity. These frogs remain stationary for long periods of time, and all employ a sit-and-wait strategy to secure prey. These characteristics allow the frogs to establish strong and constant coupling of the body with the substrate. The low levels of self-generated noise obtained with the lack of body motion and/or optimised coupling might be requirements for the frog to take advantage of a highly sensitive seismic detection system. It is not implausible to suppose that vibration could be used as a means of detecting approaching prey and/ or predators, or potentially associated with con-specific recognition, or even detecting environmental cues (e.g., rainfall) that elicit behavioural responses (e.g., emergence).

Approaching predators (e.g., birds) or other frogs could cause low-frequency vibrations, which may elicit the startle and freezing responses in frogs that assist with concealing themselves from predators/ conspecifics. Detection of approaching conspecifics by their vibrations could allow frogs to prepare for subsequent behaviours, e.g., escaping or mating. These kinds of responses have been reported in studies of other anurans (Lewis & Narins 1985; Narins 1990).

For Archey's and Hochstetter's frog, neither the absence of middle ear structures nor the lack of evidence for extratympanic pathways to transmit vibrations, nor the absence of studies investigating seismic sensing in *Leiopelma* species should preclude the possibility that vibration can be sensed. Rather, uncertainty remains surrounding vibration perception and sensitivity, and the potential importance of seismic stimuli in leiopelmatid frog ecology.

5.5 Potential Impacts of Mining Specific Vibration on Leiopelmatid Frogs

We have established that vibration perception and sensitivity in Leiopelmatid frogs remains unknown but is theoretically possible. To try and understand the potential effects of mine(blast)-generated vibrations on these frogs one can only draw from studies of other anurans and from information on the presence of frogs in areas subject to vibration effects (e.g., frog populations persisting adjacent to roads and historical mining operations).

Leiopelmatid frogs may exhibit several potential responses to vibrations caused by episodic blasting during the construction and operation of the WUG. These could include:

(a) No response, either because Leiopelmatid frogs do not sense vibration at all or do not perceive it as a stimulus that requires a response.

(b) Physiological stress or flight response, resulting in increased heart rate and/ or startling in response to short duration/ high amplitude vibrations. May manifest as freezing or flight behaviour (e.g., jumping, moving away), the latter of which could potentially disrupt sensitive behaviours such as mating amplexus, or in the case of Archey's frog, abandonment of eggs during male brooding if a male moves away from a female or eggs and does not return.

(c) Dispersal response, causing movement away from an area influenced by an annoyance (i.e., blast vibrations), which may increase susceptibility to predators.

(d) Behavioural responses to anthropogenic vibration stimuli erroneously interpreted as honest environmental cues (e.g., blast vibration misinterpreted as rainfall leading to frog emergence).

Of these possible responses, (b)–(d) have the theoretical potential to cause heightened stress, avoidance behaviours, reduced/ failed reproductive output, and/ or changes in species distribution and species composition.

To explore potential responses to vibration in leiopelmatid frogs, three case studies—one of which is somewhat speculative—have been examined and analysed. These are described and discussed in detail below.

5.5.1 Frog persistence over the duration of mining operations at Golden Cross Mine, Waitekauri Valley

The Golden Cross gold mine, in the headwaters of the Waitekauri River at the southern end of the Coromandel Range was established in 1990 and operated by Coeur Gold New Zealand Limited (CGNZL) until 1998, when it was closed due to falling gold prices. The mining licence required CGNZL to maintain rigorous environmental standards and undertake regular environmental monitoring. Hochstetter's frog (*L. hochstetteri*) was chosen as a species to monitor because of the high conservation concern for this species and the sensitivity of frogs as indicator species for the 'health' of the environment (Whitaker 1999).

The population of Hochstetter's frog in the vicinity of the Golden Cross mining operation was surveyed and monitored between 1991 and 1998, which included a baseline survey in 1989 (prior to mining) and monitoring over subsequent years of mining activity (Slaven 1992; Slaven 1994; Whitaker 1996; Whitaker 1999). Key findings of this long-term study indicated that:

- The relative abundances and densities of frogs within the study streams varied markedly over the nine-year (1989–1998) period and these variations were most likely the result of sampling bias rather than changes in actual numbers of frogs.
- The population structure (i.e., the proportion of frogs in each size class) changed significantly over the study period. Initially, the decline in the proportion of juvenile frogs and increasing proportion of adult frogs was interpreted as evidence of declining recruitment and an increasingly aging population (Slaven 1994; Whitaker 1996). However, Whitaker (1999) subsequently reported an increased proportion of sub-adults in the final 1998 survey, suggesting that the observed changes in age structure were the result of actual (natural) fluctuations in recruitment (possibly the result of regional climatic variations) rather than consequences of mining activities or monitoring methodology.
- Whitaker (1996) dismissed vibration effects on frog populations as a result of mining operations as being irrelevant.
- Whitaker (1999) concluded that there was no evidence to suggest that the mining operations had any impact on Hochstetter's frog populations or their habitat in the study streams.

In summary, this study showed that Hochstetter's frog populations at the Golden Cross mine study sites fluctuated naturally over the period of mining operations and that frog populations persisted in the vicinity of mining operations, which included activities such as drilling and blasting, over a seven-year period between 1991 and 1998.

More recent records of Hochstetter's frog from 2008 and 2023, from areas in the vicinity of the original frog monitoring sites (DOC Bioweb Herpetofauna database, accessed April 2022; OGNZL unpub. data), indicate that Hochstetter's frogs continued to persist in the general location post-mine closure. Furthermore, Archey's frog is also known from the same locations. Archey's frog was first recorded there in 1986 and subsequently recorded in 2004 and again in 2011 (DOC Bioweb Herpetofauna database, accessed April 2022) (Figure 5.4). These records indicate that Archey's frog persisted at the site, and by inference were subjected to the same mining disturbances, alongside Hochstetter's frog over the duration of the mining operations. However, there is no information on the population trends of Archey's frog between 1991 and 1998 because this species was not monitored as part of the mining licence.

More recently, Heilig & Partners assessed the surface vibration effects associated with blasting at the historical Golden Cross mine (Lane 2021). They modelled magnitude distribution curves and vibration contours associated with production blasting (open pit and underground mine) and vibration contours were overlaid with Hochstetter's frog locations recorded during the operating life of the mines to determine influence of vibration on frog populations (Figure 5.5). At the frog location most affected by blast vibration ('Location 1'), 41–50 frogs were subjected to amplitude values of approximately 4–10 mm/s over the life of the mine. However, the vibration magnitude distribution curves indicated that while 'Location 1' may have experienced one blast that caused a vibration up to 10 mm/s, such magnitude of vibration was not typically generated. Indeed, most often (500 times), blasts generated vibration in the 1–1.5 mm/s range, with most blasts generating vibrations no greater than about 4 mm/s (Lane 2021). Since Archey's frog was known to occur in the vicinity of the mine and indeed, occurred within the modelled 2 mm/s vibration contour, it is safe to assume that Archey's frog populations were subjected to vibration values of at least 2 mm/s during the life of the mine.

Vibration amplitude values ranging from 4 to 10 mm/s are highly unlikely to cause the movement or dislodgment of rocks or other objects in streams or on the forest floor where frogs may be taking refuge (Heilig & Partners, pers. comm. 2024). Consequently, there is no reasonable risk of injury or mortality to frogs resulting from the movement or dislodgment of objects due to blast vibrations. In the case of Hochstetter's frogs, which inhabit dynamic streamside environments, natural movements of rocks, boulders, and organic debris (such as branches and logs) during flash floods are relatively common phenomena that these frogs are accustomed to. Furthermore, since Hochstetter's frogs have persisted, despite episodic blast vibrations, near the Golden Cross mine, and there is no evidence indicating that mining operations have adversely affected their populations or habitat quality, the risk of injury or mortality to frogs from blast-induced object movement is considered negligible.

Overall, data from the long-term study on Hochstetter's frogs, along with the confirmed presence of both Hochstetter's and Archey's frogs at the same locations post-mine closure, indicates that both species persisted despite exposure to mine blasts and other mining activities. There was no evidence suggesting that these frogs dispersed from or perished in areas subjected to vibrations up to 10 mm/s. Moreover, the monitoring data for Hochstetter's frogs showed no indications of even temporary effects, such as local population declines, avoidance behaviours, or dispersal in the immediate vicinity of the mining operations.

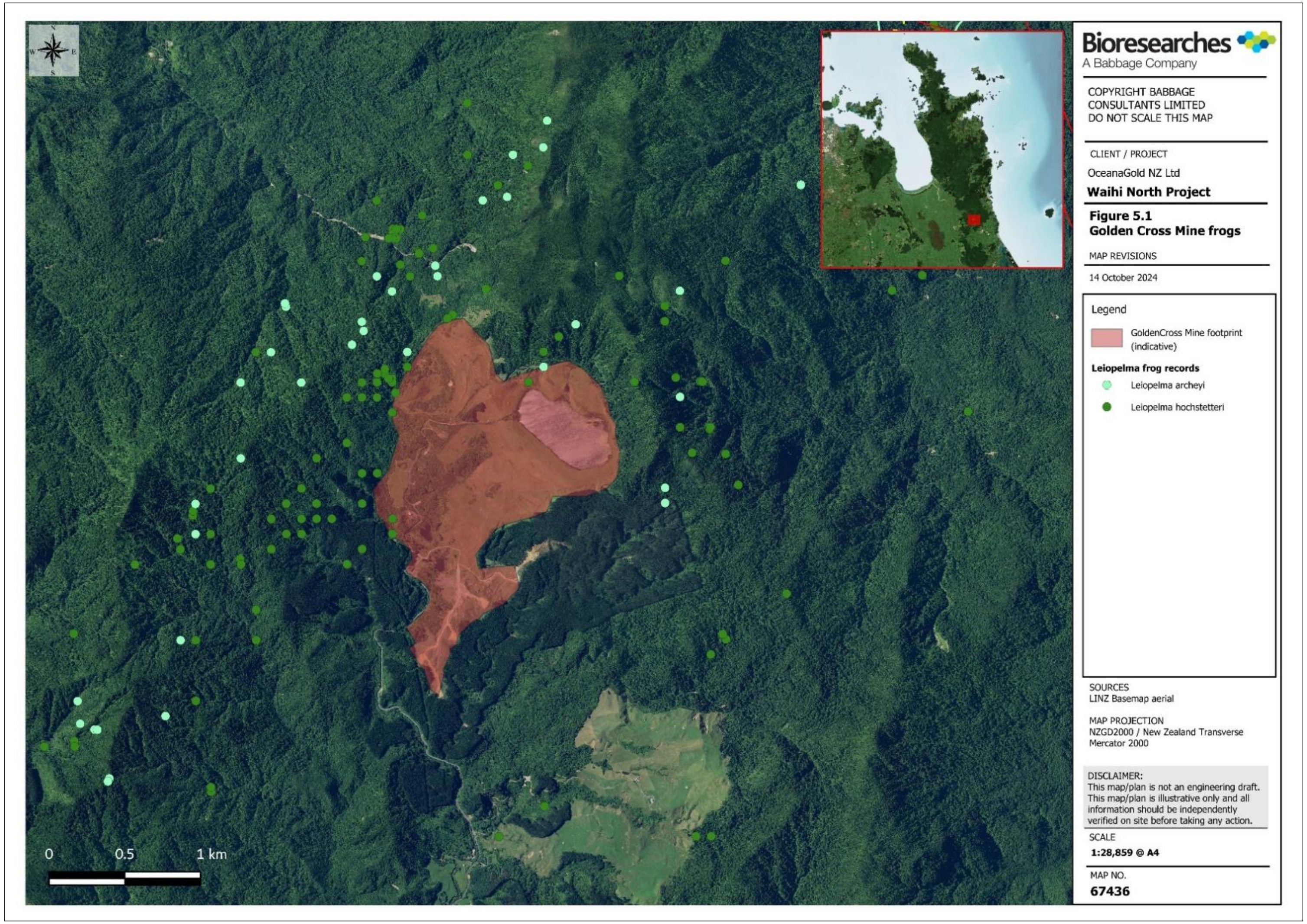


Figure 5.4. Distribution of *Leiopelma* frog records (Hochstetter's and Archey's frog) surrounding the historical Golden Cross Mine. Records sourced from DOC Bioweb Herpetofauna Database (accessed 2023).

Figure 5.5. Modelled vibration levels and associated vibration contours from blasting at Golden Cross Mine. Hochstetter's frog records (shown as number of frogs sighted in discrete areas) are overlaid.

5.5.2 Frog presence at sites subject to roadside vibration

Due to the paucity of sites to accurately measure mining vibration effects against leiopelmatid frog presence/ abundance, surface vibrations at a selection of roadside sites where leiopelmatid frogs (either Archey's frog or Hochstetter's frog) are known to occur were explored. The objective of the investigation was to determine the level of surface vibration experienced by frogs due to road traffic, with road traffic vibration considered as a proxy for the potential impacts of mine-generated vibration stimuli. Heilig & Partners (2021) justified the direct comparison between road vibration and mining vibration by commenting that as long as there is consistency between vibration parameters (amplitude, frequency, duration, and frequency of occurrence) in studies comparing vibration data from various sources, then the vibration could be considered consistent and the impacts interchangeable (i.e., vibration from traffic sources could be like that from the proposed future mine blasting).

A tri-axial geophone (vibration sensor) was installed at four roadside sites in the Coromandel Ranges (309 Road, Kopu-Hikuai, Tapu-Coroglen, and Kennedy Bay Roads) and one site in the Brynderwyn Ranges (SH1) in late September 2021 and early February 2022, respectively (Heilig & Partners 2021; OceanaGold NZ Limited 2022). At the Coromandel sites, geophones were placed between 1.8–5 m from the edge of the carriageway (i.e., the solid white line on the outer edge of the road) and a range of vibration amplitude values between 0.8–1.9 mm/s were recorded during daylight hours (Heilig & Partners 2021). In the Brynderwyn Ranges, the geophones were placed between 0.5–5.6 m from the edge of the carriageway and maximum vibration amplitude values of 0.7–2.1 mm/s were recorded during daylight hours (OceanaGold NZ Limited 2022).

Archey's frogs have historically been reported at 10 m or greater from the road edge (DOC Herpetofauna database, accessed April 2022), but more recent surveys of Coromandel sites recorded frogs at 4 m from the road edge (Boffa Miskell, unpub. data) and Hochstetter's frogs were recorded 10 m from road edge in the Brynderwyn Ranges (Bioresearches, unpub. data). At these distances, frogs may be subject to vibration values of <2 mm/s based on the current vibration data. While surveys did not detect frogs any closer to the road edge this was most likely an artifact of habitat quality (i.e., lower quality habitat and habitat subject to edge effects, e.g., increased light penetration, higher temperatures, and lower humidity) on road edges rather than avoidance of traffic vibration. However, this presumption has not been scientifically demonstrated. Since the road vibration data was not collected from sites where frogs were specifically found, this work should be considered a preliminary investigation into road vibration effects on frogs.

5.5.3 Archey's frog reproduction and captive breeding at the Auckland Zoo

The breeding biology of Archey's frog, described in detail by Bell (1985), involves a period after egg-laying whereby the male guards (broods) the eggs for several weeks until they hatch. Egg brooding in Archey's frog is characterised by a male sitting high over the eggs with body raised and both fore- and hind-limbs outstretched. Once the eggs hatch, the tiny, tailed froglets climb onto the back of the male who carries them for several weeks while they complete their development (dorsal brooding). It is still unclear what function the male brooding and dorsal brooding is, but it has been postulated that these behaviours are possibly related to maintaining a moist micro-environment for the eggs and tadpoles in a 'dryer' terrestrial environment (Stephenson 1961; Salthe & Mecham 1974; Bell 1985). In the absence of sufficient moisture, eggs fail to develop successfully (Bell 1985). Brooding may also be a strategy to reduce the incidence of fungal and bacterial infection, and/ or protect the eggs/ froglets from predators. Notwithstanding the importance of male brooding, successful larval development from eggs to froglets in the absence of a male has been demonstrated in captivity, providing eggs and larvae are kept moist (Bell 1985; Auckland Zoo, unpub. data).

Irrespective of the function of brooding, this stage of the breeding cycle is clearly a sensitive time in the lifecycle of Archey's frog and is important for the successful recruitment of viable young in the wild. Moreover, the K-selected reproductive strategy of Archey's frog (i.e., a reproductive strategy characterised by slow maturation, low reproductive output, and living for a long time) means it is in the best interest for the male to protect 'his' eggs and progeny through to metamorphosis.

The key question is whether disturbance to brooding males leads to egg abandonment, and if so, what type and level of disturbance can a male frog tolerate before abandoning his eggs? Additionally, if abandonment occurs, does the male possess an innate behavioural drive to return to his eggs? While these specific questions have not been directly addressed in research studies, anecdotal evidence from both field observations and a captive Archey's frog facility suggests that brooding males may be tolerant to some low-level disturbance. Revealing brooding males by lifting natural refuge structures in the field to observe egg development, as well as zoo staff moving around the captive Archey's frog facility and lifting artificial refuges to closely monitor egg development in captivity will have frequently disturbed frogs. In captivity, despite these frequent disturbances, successful natural brooding through to metamorphosis was consistently observed (Auckland Zoo, unpub. data). In the field, Bell (1985) reported that two male Archey's frogs maintained their brooding posture for up to 17 days, even when gently "prodded", after being collected off egg clusters just before their eggs hatched. These observations suggest that male frogs exhibit a strong innate behavioural predisposition to continue brooding, even when subjected to disturbance.

In captivity, unfertilised eggs and egg abandonment was recorded on several occasions (Auckland Zoo, unpub. data). Several potential explanations for these recruitment failures have been considered, including the possible impact of anthropogenic vibrations within the custom-designed shipping container housing Archey's frogs at Auckland Zoo. It was reported that a broken floor support and movement in the floor panels, caused by keepers moving around inside the facility, led to frequent vibrational disturbances (R. Gibson, pers. comm., January 2022). While these vibrations may have contributed to the increased rates of egg clutch abandonment observed, this hypothesis remains largely speculative, and no measurements were taken to determine the extent of any increased vibration experienced by the frogs.

The effects of anthropogenic vibrations on captive animals have been documented in the literature. Garner *et al*. (2018) reported behavioural responses in laboratory rodents to vibration caused by routine husbandry procedures and Felt *et al.* (2012) demonstrated morbidity and mortality in aquatic African clawed toads in a laboratory setting in response to adjacent construction vibration. As such, potential vibration effects on Archey's frogs at Auckland Zoo cannot be completely dismissed but it is more likely that other influences such as unnaturally high stocking densities (i.e., multiple frogs per m^2) may have been a larger contributing factor to lowered breeding success in the captive frogs (Auckland Zoo, unpub. data).

Although there is limited information on the behaviour and movements of male Archey's frogs while brooding eggs, it is likely that some movement occurs, as egg-brooding frogs have been observed to defecate, indicating they have fed despite their brood care responsibilities (Bell 1985). If frogs can temporarily move away from their eggs to feed and then return, it seems plausible that a male frog might respond to an extraneous disturbance, such as vibration, by briefly leaving the egg cluster. Given their significant investment in caring for their eggs and ensuring successful recruitment, it is likely they would return to brooding shortly after the disturbance subsides. Moreover, disturbance effects—such as startle responses or intentional movement—during the dorsal brooding phase may be less consequential, as males are more mobile and can carry the froglets on their backs during this period.

6 DEWATERING EFFECTS ON NATIVE FROGS

6.1 DEWATERING AND POTENTIAL EFFECTS ASSOCIATED WITH THE PROPOSED WHAREKIRAUPONGA UNDERGROUND MINE

The Wharekirauponga Underground Mine associated with the Waihi North Project (WNP) proposes to mine a deep vein system in the Wharekirauponga catchment, which would result in deep groundwater dewatering. Potential drainage of the shallow groundwater system (groundwater drawdown) could reduce surface water discharges to streams and have a range of ecological effects, some of which may include:

- Surface water impacts – dewatering can affect surface water bodies by lowering water levels or altering flow patterns that can disrupt aquatic habitats and species that rely on these habitats (e.g., aquatic or amphibious taxa).
- Groundwater depletion – dewatering can lower the water table, leading to decreased groundwater availability for nearby forests. This can stress forest ecosystems, particularly during periods of drought, potentially leading to reduced tree growth, altered soil moisture levels, and changes in terrestrial species composition.
- Soil disturbance – the extraction of water can lead to soil compaction and erosion. Soil disturbance can negatively affect the health of forest ecosystems by reducing soil fertility, disrupting nutrient cycling, and increasing susceptibility to erosion and landslides.
- Loss of biodiversity – the cumulative impacts of dewatering on forest ecosystems could result in the loss of biodiversity. Species that are particularly sensitive to changes in hydrology, water quality, or habitat availability may decline or disappear from affected areas, leading to decreased overall biodiversity and ecosystem resilience.

Hochstetter's frog populations are known occupy the watercourses and riparian margins in the Wharekirauponga catchment and Archey's frog populations are known to occupy the surrounding forested areas. Dewatering as part of the Wharekirauponga Underground Mine could potentially impact frog populations if changes to stream or forest characteristics are realised. Changes to soil moisture levels, the drying of nearby wetlands or ground-fed streams, potential changes to forest composition and type (e.g., reduced moisture leading to altered or less preferable forest types for frogs), and reduced water flow and/ or wetted width could potentially affect frog habitat availability.

To assess the potential effects of dewatering on native frog populations, a variety of hydrological reports were reviewed[15] and interpreted alongside ecological and behavioural information available for Leiopelmatid frogs. Technical reports reviewed as part of the frog assessment included:

[15] Information associated with potential surface water impacts stemmed from a water balance model (WBM) developed by GHD, that captures the current continuous flow monitoring locations within the Wharekirauponga catchment. This information was used in the frog assessment, and thus the limitations and assumptions outlined by GHD 2025 are also relevant to the frog assessment.

- Flo Solutions (2024a, 2024b) – Conceptual groundwater model and numerical modelling.
- Intera (2024) – Model calibration and sensitivity analysis.
- GHD (2025) – Hydrology modelling.
- WWLA (2025a, 2025b, 2025c) – Regional hydrogeologic setting, wetland delineation and drainage effects.
- NIWA (2024) – Instream habitat (for aquatic fauna) of the Wharekirauponga Streams and tributaries.
- Boffa Miskell (2016, 2018, 2019a, 2019b, 2020, 2021, 2022, 2024, 2025a) – Ecological and Freshwater environment effects.
- Bioresearches (2025) – Wetland delineation and dewatering effects assessment.

The frog assessment focusses primarily on semi-aquatic Hochstetter's frogs, which are largely reliant on streams and flowing water to complete their lifecycle. However, the potential effects of dewatering on terrestrial Archey's frogs are also discussed.

6.1.1 Dewatering and surface water effects

Several aspects of dewatering have been identified as potentially impacting frogs, including reductions in stream flow, decreased wetted width, potential effects on forest and riparian vegetation, impacts on spring-fed watercourses, and changes to instream habitats that support invertebrate prey. Although these factors are interrelated, they have been separated for the purpose of this assessment, with the potential effects of each on frog populations evaluated individually.

6.1.1.1 Flow reduction

Water flow is a key factor in determining habitat availability in streams and rivers, which directly impacts the composition and distribution of aquatic life. Aquatic and semi-aquatic species have evolved life history strategies that are closely tied to the natural flow regime. Any disturbance to this flow such as reduced water velocity or change in water depth can reduce habitat availability, disrupt the life cycles of organisms, and negatively affect the structure (e.g., diversity and abundance of organisms) and health of aquatic ecosystems (Lake 2003; Power *et al*. 2013; Kaylor *et al.* 2019; Szałkiewicz *et al*. 2022).

Furthermore, reduced water velocity can lead to increased fine sediment deposition, which can clog interstitial spaces between substrates thereby reducing habitat quality. Indeed, Hochstetter's frogs occur much less frequently in silted, compared to unsilted, streams. Reduced flow may slow the downstream movement ('flushing') of organic debris and food resources, reducing refuge habitat and food availability for a variety of organisms, including Hochstetter's frog.

Significantly reduced flow can also affect the physicochemical properties of water by altering contaminant concentrations and water temperature. Water temperatures may increase due to faster warming in summer or decrease as a result of substantial groundwater recharge to the watercourse. These temperature fluctuations, in turn, affect dissolved oxygen levels, to which certain taxonomic groups are particularly sensitive (Szałkiewicz *et al.* 2022).

Hochstetter's frogs show a strong preference for cool, shaded, unsilted streams with relatively fast-flowing water. Reductions in flow that lead to elevated water temperatures and increased siltation could degrade the quality of their habitat. The impact of physical habitat changes on stream organisms depends on the species' specific responses to such changes, the severity and duration of reduced flows, and the availability of thermal and habitat refugia (Walters 2016; Kaylor *et al.* 2019) (see *Section 6.1.2: Instream habitat assessment and implications for frogs*).

6.1.1.1.1 Predicted baseflow reduction in surface water in Wharekirauponga

Groundwater modelling suggests that mine dewatering could potentially affect surface water through baseflow losses from streams (GHD 2025). The modelling indicates the following:

- The post-mining scenario could influence the flow regime to varying degrees in different sub-catchments, with the percentage reduction between the pre-mining and post-mining scenarios greatest during low flow conditions at all sites (e.g., MALF[16], 7-day MALF[17]) (GHD 2025).
- Model results predict the 7-day mean annual low flow (7-day MALF) could be reduced by between 2 to 13%, and this would be largely restricted to areas immediately above the Wharekirauponga Underground Mine and down catchment of this area (Figures 6.1 and 6.2).
- Modelled reductions would only be realised for short time periods (during prolonged dry spells).
- The modelled reductions in MALF do not significantly depart from the current calculated MALF and are unlikely to significantly affect the flow variability currently observed from year to year, which exhibits significant variation in annual low flow (ALF) (i.e., reduced flows are within the current natural variation observed). The exception to this is within the Thompsons sub-catchment and to a lesser extent Edmonds sub-catchment where the modelled reductions in MALF (as a result of the Wharekirauponga Underground Mine development) approach the lower end of the estimated ALF variability (GHD 2025). That is, the Thompsons and Edmonds sub-catchments will experience the largest reductions in 7-day MALF because they represent smaller tributaries located above the proposed Wharekirauponga Underground Mine area (Figure 6.2).
- The modelled results are conservative for reasons outlined by GHD (2025) (and summarised by WWLA 2025b).

[16] Mean annual low flow (MALF) = where the lowest flow for each (hydrological) year is averaged over the data record available.
[17] 7-day Mean annual low flow (7-day MALF) = the lowest flow over a 7-day rolling average for each (hydrological) year, averaged over the data record available.

- Groundwater level recovery, as predicted by the numerical groundwater model has indicated it would take 10 years after the cessation of pumping associated with mining for the groundwater levels to recover to 90% of the preexisting levels, with full recovery expected within 20 to 30 years.
- Since the predicted reductions in surface water flow are within the range of natural seasonal variation, potential effects on surface water (not accounting for ecological processes or effects) are considered low.

Of the nine stream sub-catchments, the Edmonds and Thompsons are predicted to potentially experience the largest reductions in flow. Reductions in the 7-day MALF in the Edmonds Stream of 10.8% [Mean] or 11.5% [5th%ile] are predicted. Whereas, the 7-day MALF in the Thompson Stream is predicted to reduce by 11.5% [Mean] or 12.4% [5th%ile] (GHD 2025). Hochstetter's frogs are known to occur widely in both the upper and lower stream reaches of the Edmonds sub-catchment, and while there are no existing Hochstetter's frog records from the Thompsons sub-catchment, it is conservatively assumed that frog populations are present.

While reductions in the 7-day MALF of up to 12.4% could be seen as having measurable impacts on Hochstetter's frogs (e.g., due to siltation and reduced habitat quality), it's important to note that these predicted reductions remain within the range of natural variation observed in ALF—recognising that the modelled reductions for Edmonds and Thompsons approach the lower end of estimated ALF variability (GHD 2025). Additionally, these flow reductions are expected to occur only during brief periods, such as extended dry spells. Hochstetter's frogs will be naturally familiar with seasonal variation in stream flows and will have adapted behavioural strategies to cope with low flow (e.g., selecting refuges close to the lowered waterline). Because the predicted reductions remain within the range of natural variation observed in ALF, impacts of flow reductions on Hochstetter's frogs in streams above the proposed Wharekirauponga Underground Mine and within the wider Wharekirauponga catchment area are not anticipated.

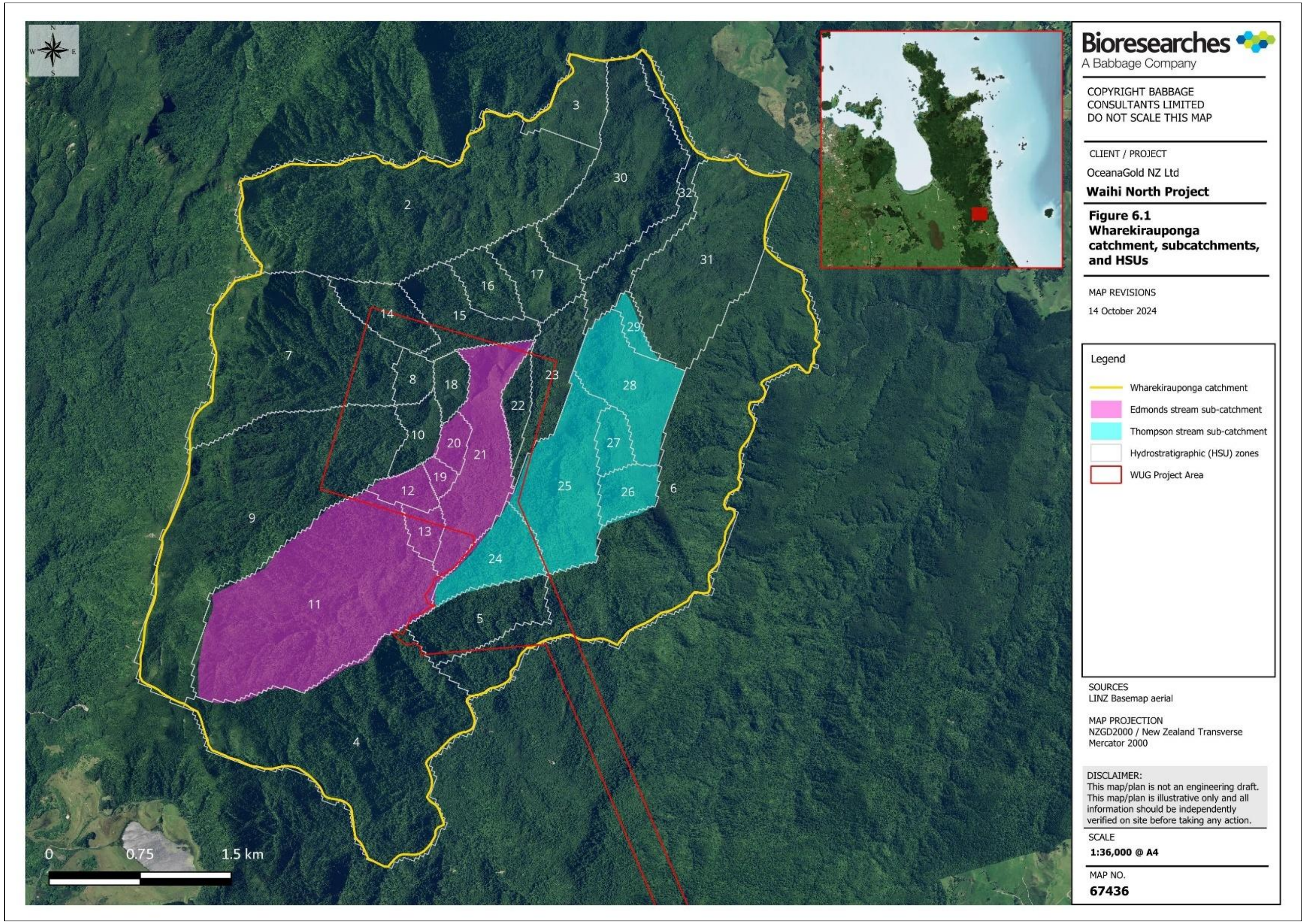


Figure 6.1. Location of the Wharekirauponga Underground Mine in relation to the Wharekirauponga catchment and the Thompson and Edmonds sub-catchments referred to in the text above.

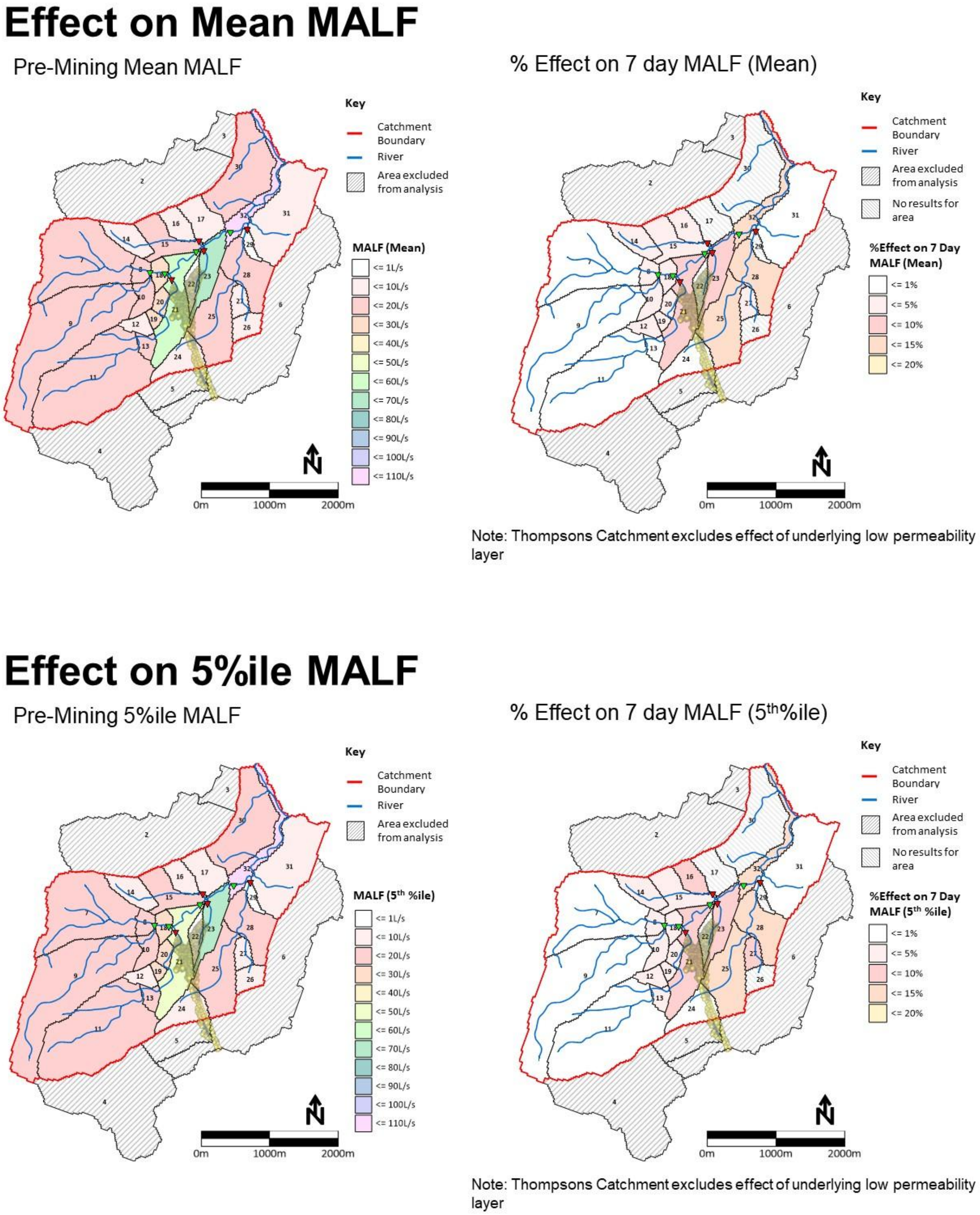


Figure 6.2. Dewatering effects on mean MALF (expected scenario) and 5th% MALF (worst case scenario) for pre- and mining situations. Sourced from GHD (2025).

6.1.1.2 Wetted width reduction

The wetted width of a stream or river is defined as the distance between the sides of the channel at the point where substrates are no longer surrounded by surface water. Wetted width is directly important to biological conditions as it controls the total area available for bottom-living organisms. That is, it is an important measurement in understanding the physical and ecological habitat availability for a variety of aquatic taxa (e.g., periphyton, macroinvertebrate and fish) (NIWA 2024). For semi-aquatic taxa such as Hochstetter's frog that move freely along the edge of the waterline, it is expected that changes to wetted width will have much less influence on habitat availability compared to the influence on aquatic species.

6.1.1.2.1 Predicted wetted width reduction in Wharekirauponga

Changes in wetted width predominantly occur as a result of changes in flow (MfE 1998), and based on the current mine design, potential wetted width reductions under the worst case (unlikely) scenario may be realised due to baseflow losses in streams (GHD 2025).

The modelled reductions in wetted width are outlined in detail by GHD (2025). The models predict potential reductions in wetted width of 0–5% of the 7-day MALF across the affected sub-catchments during periods of low flow, with the Edmonds and Thompson Stream sub-catchments predicted to be most affected (Figure 6.3). Table 6.1 shows wetted width reductions predicted for the nine affected sub-catchments and Table 6.2 shows wetted width reductions predicted for the five worst affected HSUs. It is important to emphasise that reductions in wetted width will not be realised in the environment often. During periods of normal (average), medium and higher flows, much smaller or no such wetted width reduction is modelled to occur. The modelled reductions in wetted width are considerably smaller than the relative reduction in flow based on the flow/ wetted width relationship, which only sees significant reductions in wetted width (for reduction in flow) as the flow approaches zero (GHD 2025).

To conceptually demonstrate the potential effects of reduced wetted width at low flow on Hochstetter's frogs, a worse-cast 5% reduction was applied to a 2-metre-wide stream. This resulted in a 100 mm decrease in wetted width (Figure 6.4). Since Hochstetter's frogs typically inhabit a broad streamside margin—up to a metre or more on either side of the waterline—this small decrease in wetted width represents only a minimal reduction in available habitat. In fact, in streams with gently sloping banks, the decrease in wetted width may expose additional damp substrate, potentially providing more areas for foraging and refuge for the frogs.

Given the small, predicted reductions in wetted width, the relatively wide streamside margins that Hochstetter's frogs inhabit, and their ability to move freely to more favourable conditions along a stream, it is highly unlikely that any significant impacts on the resident frogs above the Wharekirauponga Underground Mine will result from potential reductions in wetted width. Since wetted width reductions are not expected outside of the Wharekirauponga catchment, populations of Hochstetter's frogs in the surrounding areas will remain unaffected.

Table 6.1. Sub-catchment level wetted width reduction percentage pre- vs post mining. Sourced from GHD (2025).

Percentage reduction (wetted width) between pre mining and mining - Probabilistic Scenario (5th %ile and average results)																		
	TStreamW		TStream E		Edmonds		Trib R		Adams		WKP 03		WKP 02		Thompson		WKP 01	
	5%ile	Mean	5%ile	Mean	5%ile	Mean	5%ile	Mean	5%ile	Mean	5%ile	Mean	5%ile	Mean	5%ile	Mean	5%ile	Mean
Average flow	0.1%	0.1%	0.2%	0.2%	0.7%	0.7%	0.2%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.9%	0.7%	0.4%	0.3%
MALF	0.5%	0.4%	1.1%	0.9%	3.4%	3.2%	1.3%	1.6%	1.4%	1.3%	2.1%	1.9%	2.1%	1.9%	3.6%	3.3%	1.9%	1.7%
7day-MALF	0.4%	0.4%	1.0%	0.8%	3.0%	2.9%	1.1%	1.5%	1.3%	1.2%	1.8%	1.7%	1.8%	1.7%	3.3%	3.1%	1.7%	1.6%

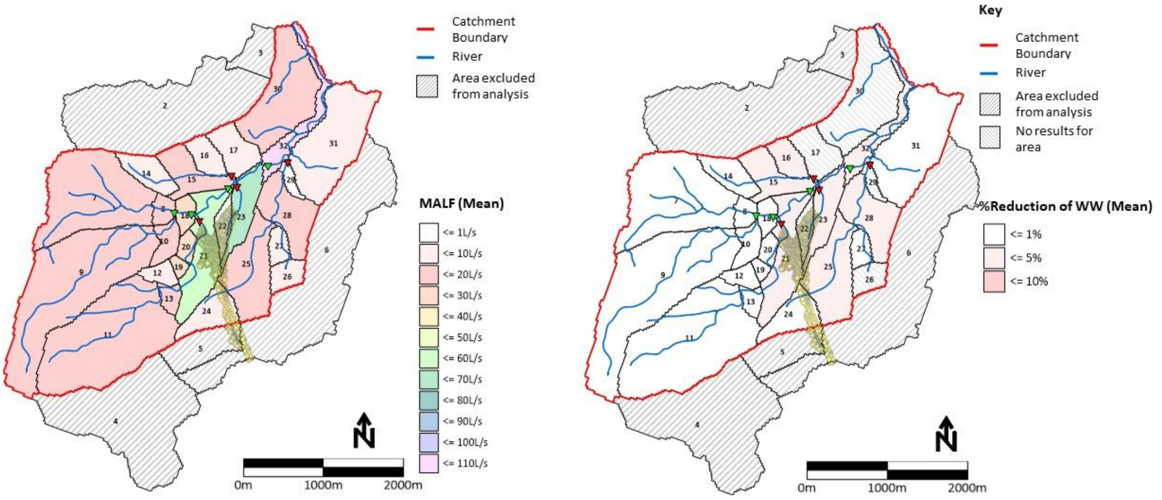
Table 6.2. HSU level wetted width. Five HSUs with largest potential wetted width reductions. Sourced from GHD (2025).

Percentage reduction (wetted width) between pre mining and mining - Probabilistic Scenario (5th %ile and average results)										
	HSU20		HSU21		HSU22		HSU25		HSU28	
	5%ile	Mean	5%ile	Mean	5%ile	Mean	5%ile	Mean	5%ile	Mean
Average flow	?	?	0.4%	0.4%	?	?	1.2%	1.0%	0.9%	0.8%
MALF	?	?	2.1%	1.9%	?	?	4.1%	3.8%	3.8%	3.5%
7day-MALF	?	?	1.8%	1.7%	?	?	3.9%	3.6%	3.5%	3.2%

Effect on Mean Wetted Width

Pre-Mining Mean MALF

% Effect on Wetted Width (@ 7 day Mean MALF)

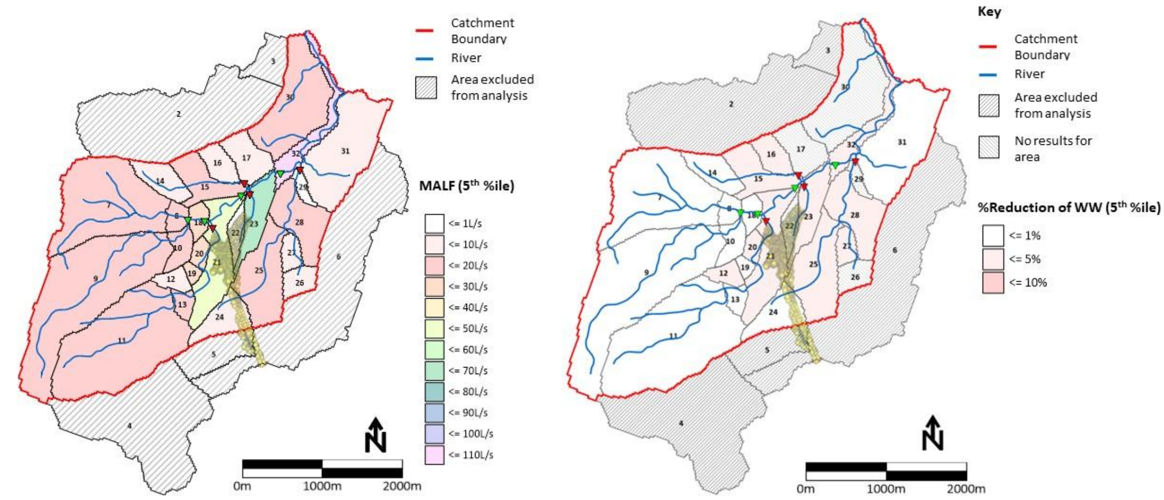


Note: Thompsons Catchment excludes effect of underlying low permeability layer

Effect on 5% Wetted Width

Pre-Mining 5%ile MALF

% Effect on Wetted Width (@ 7 day 5%ile MALF)



Note: Thompsons Catchment excludes effect of underlying low permeability layer

Figure 6.3. Dewatering effects on mean wetted width (expected scenario) and 5^{th}%ile wetted width (worst case scenario) for pre- and mining situations. Sourced from GHD (2025).

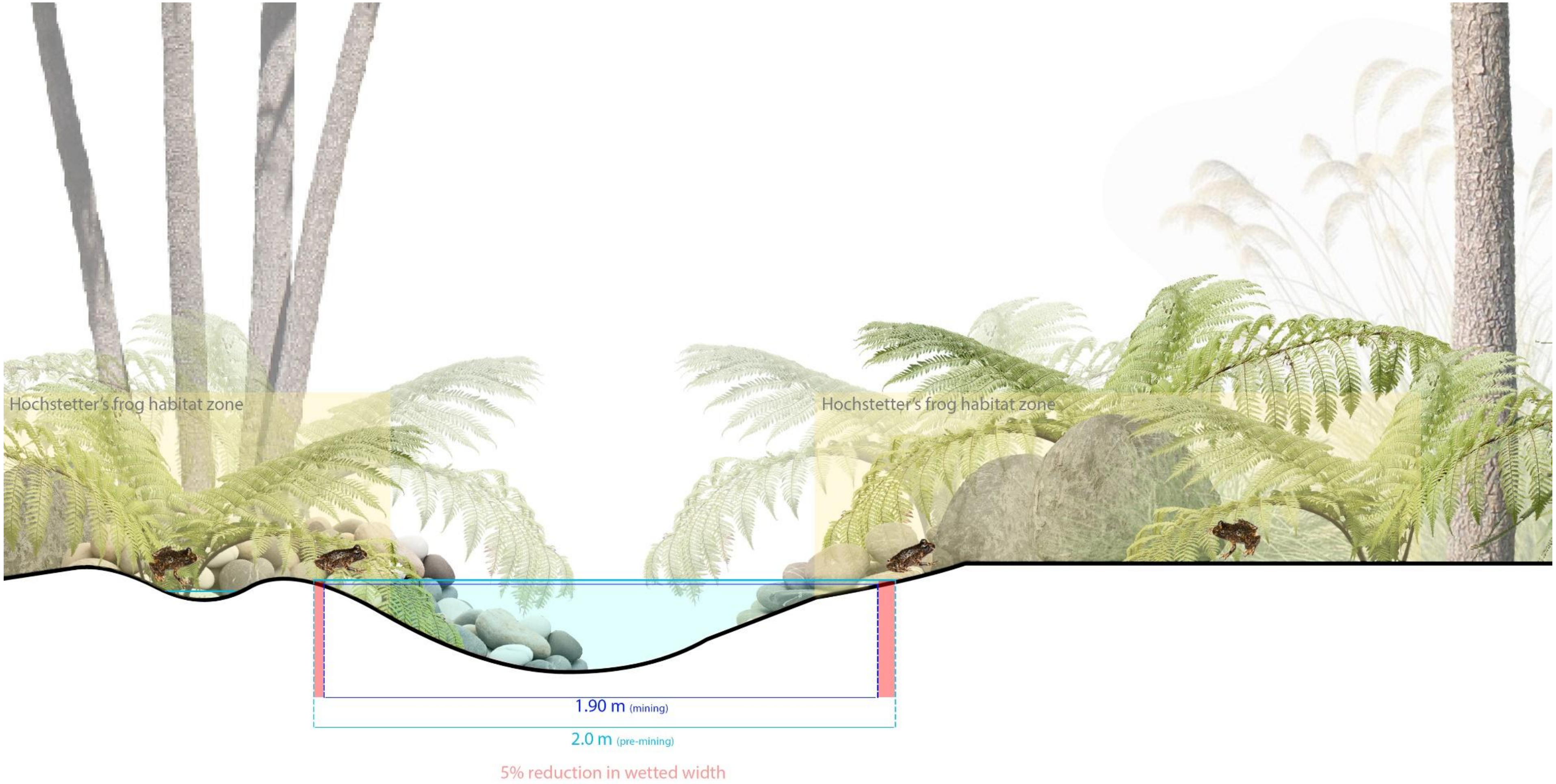


Figure 6.4. Cross section of forest stream showing the influence of a worst-case 5% reduction in wetted width at low flow, due to potential baseflow reduction during mining, on Hochstetter's frog habitat.

6.1.1.3 Forest vegetation effects

When dewatering lowers groundwater levels in the shallow aquifer system, it can reduce groundwater availability for forest, riparian, or wetland ecosystems. In extreme cases, where groundwater depletion persists over extended periods and coincides with low rainfall (e.g., during droughts), vegetation communities may experience stress, potentially leading to altered soil moisture levels, reduced plant growth, and changes in species composition and behaviour.

Vegetation cover plays a crucial role in shading forest floors and streams, helping to maintain lower temperatures and high relative humidity (Sugimoto *et al*. 1997). Riparian vegetation also provides significant organic matter inputs that sustain stream food webs, where species like Hochstetter's frogs occupy an intermediate trophic level (Nájera-Hillman *et al*. 2009a, b). Any reduction in riparian vegetation within catchments where Hochstetter's frogs occur may negatively impact their populations. Similarly, decreased soil moisture and reductions in forest vegetation or relative humidity could degrade the quality of forest habitats for terrestrial species such as Archey's frog.

6.1.1.3.1 Anticipated effects of dewatering on forest vegetation in Wharekirauponga

Groundwater modelling predicts that the extraction of deep groundwater for mine dewatering is expected to have minor or negligible effects on groundwater levels in the shallow aquifer system (WWLA 2025b). This is because the deep ("EG Vein") aquifer is considered to be disconnected or very weakly connected to the shallow aquifer (Flo Solutions 2024a, b; WWLA 2025b). Accordingly, soil moisture that supports surface vegetation and frog habitat is predominantly rainfall derived and is not expected to be adversely affected by deep groundwater changes. As a result, adverse effects on the habitat quality and quantity, and populations of Hochstetter's and Archey's frogs due to dewatering are not anticipated.

6.1.1.4 Effects on springs and rainfall fed seeps/ streams

Hochstetter's frogs favour lower-order (first and second) streams and seepages in headwater catchments as their primary habitat (Nájera-Hillman *et al.* 2009b). These upper catchment streams and seeps are typically fed by rainfall or springs. Springs form when the water table intersects the earth's surface or when groundwater rises through rock faults, fractures, or depressions (Death *et al*. 2004). A unique feature of springs is their role as a three-way interaction zone between groundwater, surface water, and terrestrial ecosystems (Scarsbrook *et al*. 2007), often creating groundwater-dependent ecosystems (Hatton & Evans 1998). Springs that discharge into small seeps, which may turn into springbrooks (small overland flow paths created by a spring), provide the moist conditions essential for species like Hochstetter's frog.

If dewatering affects groundwater levels in the shallow aquifer system, it could lead to reduced or ceased water flow from springs, thereby altering springbrook and small stream flows. This reduction in flow could diminish the availability of suitably damp habitats required by Hochstetter's frogs.

6.1.1.4.1 Predicted effects on springs in Wharekirauponga

Hydrological assessments conclude that interflow and contact springs will not be impacted by the proposed mine dewatering, as they are fed by shallow water movement sourced from rainfall (WWLA 2025b). Therefore, the spring-fed seeps, springbrooks, and streams throughout Wharekirauponga, which currently provide habitat for Hochstetter's frogs, will remain unaffected by the dewatering. This conclusion also applies to most non-spring-fed streams, where water is primarily sourced from rainfall rather than shallow groundwater. As a result, these streams—and the resident Hochstetter's frogs and their habitats—will not be impacted by the dewatering.

There are two exceptions where spring flows are expected to decrease due to dewatering effects. At a single downstream reach discharge location, a temporary reduction of 5 L/s in fracture-controlled discharge is anticipated for the duration of the mine dewatering. This spring feeds into a larger downstream reach of the Wharekirauponga Stream, and while Hochstetter's frogs may be present downstream, a 5 L/s reduction in flow is unlikely to adversely affect the frogs or their habitat, as sufficient water flow will remain in the stream despite reduced flow. As noted earlier, this reduction in discharge will be temporary, with flow levels expected to return to normal discharge levels as the mine rewaters to its natural state (WWLA 2025b).

Another spring, known as "Warm Spring," has been identified as being affected by dewatering. At this discharge point, approximately 3.5 L/s of flow is conservatively expected to cease for the duration of the mine dewatering. This flow is unlikely to return once the mine rewaters, as the pathway from deep groundwater to the surface is expected to be disrupted by mining activities (WWLA 2025b). However, it is possible that a cold spring may emerge at the same location once rewatering occurs. Despite the likely permanent—or potentially temporary—reduction in discharge at this site, the impact on Hochstetter's frogs is considered negligible. The Warm Spring currently discharges directly into the main channel of the Wharekirauponga Stream and therefore, does not sustain stream flow or provide critical frog habitat.

6.1.2 Instream habitat assessment and implications for frogs

National Institute of Water and Atmospheric Research/ Taihoro Nukurangi (NIWA) was engaged by OGNZL to determine the effect of dewatering on instream habitat for aquatic organisms (assessed taxonomic groups included periphyton, invertebrates, and fish) in the Wharekirauponga Stream and its tributaries above the proposed Wharekirauponga Underground Mine. An interpreted summary of their findings is provided here but the reader should refer to the NIWA (2024) for a detailed description of the methods, assessment results, and expert interpretation.

This section of the report outlines the summary findings of the instream habitat assessment, carried out by NIWA (2024), as they relate to the Edmonds and Thompson Streams[18] and potential effects on semi-aquatic Hochstetter's frogs.

[18] Edmonds and Thompson Streams are the focus because this is where the greatest predicted surface water effects would be realised, according to modelled mine dewatering scenarios and flows provided by Flo Solutions and GHD.

NIWA used instream habitat modelling to determine the available instream physical habitat for a range of aquatic species/ classes and how the available habitat for these species would respond to potential changes in flow in Wharekirauponga Stream and its tributaries. This was predicted by calculating the change in 'habitat suitability' ("Area Weighted Suitability"[19]). NIWA focused results on the 'worst case' post-mining 7-day MALF as this would cause the largest reductions to instream habitat. However, they also included results of the 'average case' (i.e., most likely scenario) post-mining 7-day MALF, and the median flows (which are representative of the average annual flow conditions). The results of the predicted change of AWS for invertebrates are summarised below and in Table 6.3.

- For the average-case (most likely scenario) changes to suitable instream habitat for aquatic invertebrates between the pre-mining 7-day MALF and the predicted post-mining 7-day MALF ranged from -1.04% to -3.91% in Edmonds, Adams, and Thompson Stream sub-catchments. The average reduction of suitable instream habitat for invertebrates for the three sites was -2.55%.
- For the worst-case (unlikely scenario) changes to suitable instream habitat for aquatic invertebrates between the pre-mining 7-day MALF and the predicted post-mining 7-day MALF ranged from -1.64% to -5.28% in Edmonds, Adams, and Thompson Stream sub-catchments. The average reduction of suitable instream habitat for invertebrates for the three sites was -3.58%.
- At median flow, which is representative of average annual flow conditions, changes in flow due to mining scenarios having much less impact on suitable instream habitat than those at the 7-day MALF.
- Even for the improbable worst-case scenario of the groundwater and surface water modelling there are very small changes to suitable instream habitat for flow reductions relative to the median flow.

Since Hochstetter's frogs are semi-aquatic (they do not spend all their lives in the water column), the methods used by NIWA to calculate instream habitat change in response to potential flow changes could not be directly applied to frogs or their habitat. However, aquatic invertebrates, which likely provide a food resource for frogs, may provide a proxy for habitat quality. Changes in invertebrate communities or abundance resulting from changes in available habitat could affect frog habitat quality. That is, if potential food resources are impacted by flow and habitat reductions, then this could indirectly impact frogs living in the streams.

The results of the instream habitat modelling suggest that changes to aquatic invertebrate habitat would be minimal, even under the worst-case scenario (7-day MALF). Consequently, it is likely that aquatic invertebrate diversity or abundance would not be significantly impacted (Boffa Miskell 2024).

[19] Area Weighted Suitability (m^2/ m) is the average wetted area of a stream (per unit length) that is suitable for use by an aquatic species, or class of aquatic species.

Since Hochstetter's frogs primarily feed on terrestrial invertebrates (Stephenson & Stephenson 1957; Sharell 1966; Kane 1980; Chapman & Alexander 2006; Nájera-Hillman *et al.* 2009a; Shaw *et al.* 2012), with much less reliance on aquatic invertebrate prey, it is highly improbable that frogs living and foraging along stream edges above the Wharekirauponga Underground Mine would be affected.

Table 6.3. Percentage change of Area Weighted Suitability (AWS) for all invertebrates (showing taxa where at least 5% of available AWS is suitable at 7-day MALF) in three stream sub-catchments (Edmonds, Adams, Thompson) under post-mining scenarios.

	Percentage change from Pre-mining Median flow		Percentage change from Pre-mining 7-day MALF	
Sub-catchment	Post-mining Median flow [Average case]	Post-mining Median flow [Worst case]	Post-mining 7-day MALF [Average case]	Post-mining 7-day MALF [Worst case]
Edmonds Stream	-0.62	-1.39	-2.70	-3.82
Adams Stream	-0.42	-0.97	-1.04	-1.64
Thompson Stream	-0.95	-1.73	-3.91	-5.28

Changes to suitable instream habitat for flows around the median (more representative of annual flow conditions) are typically much less significant than those around the 7-day MALF for all study reaches and all species/classes.

7 ASSESSMENT OF ECOLOGICAL VALUES AND EFFECTS

The Ecological Impact Assessment Guidelines (EcIAG) published by Environment Institute of Australia and New Zealand (EIANZ) (Roper-Lindsay *et al.* 2018) were used to guide the ecological values and effects assessment process. The framework is based on guidelines developed by the Institute of Ecology and Environmental Management (Regini 2000; 2002). The EcIAGs provide a standardised matrix framework that provides a transparent and consistent approach to ecological effects assessments. The EcIAG framework is generally used in impact assessments in New Zealand as good practice.

The approach involves three main steps:

Step 1: Assign an ecological **value** on a scale of 'Negligible' to 'Very High' to ecosystems/ habitats and species identified within the Project area (see Table 5 and Table 6 in Appendix A).

Step 2: Determine the **magnitude** of effect each value (see Table 8 in Appendix A). This step also includes consideration of the timescale and permanence of the effect.

Step 3: Evaluate the overall severity or **level of effect** using a matrix of the ecological value and magnitude of effect (see Table 10 in Appendix A).

The EcIAG ecological value assignment process uses attributes that are broadly consistent with those commonly used for RMA s6(c) significance assessment. That is, a level of effect that corresponds to 'Moderate', 'High', or 'Very High' is generally accepted by ecologists to constitute a 'significant ecological effect' under the RMA, while a 'Low' or 'Very Low' level of effect is usually considered to correspond to a 'minor ecological effect' or 'less than minor ecological effect' under the RMA. It is generally accepted that 'Very High' levels of effect trigger avoidance or re-design.

7.1 ASSIGNMENT OF ECOLOGICAL VALUE

In assigning ecological values to Archey's and Hochstetter's frogs that occur in the potentially affected area, each frog species' New Zealand Threat Classification System listing (Townsend *et al.* 2008; Rolfe *et al.* 2022; Burns *et al.* 2025) has been considered. Since both species are listed as 'At Risk – Declining' and both occur permanently in the zone of influence (ZOI)[20], a 'High' ecological value has been assigned in accordance with criteria listed in Table 5 of EIANZ guidelines.

7.2 MAGNITUDE OF EFFECTS ASSIGNMENT

The potential effects of the Wharekirauponga Underground Mine activities on native frogs occupying the streams and forests above the mine are identified and described below, under the general themes of 'distribution and abundance', 'vibration', and 'dewatering' effects. In assigning a magnitude of

[20] Zone of influence (ZOI): area in which an activity or pressure could directly or indirectly impact part of the environment.

effect, duration and timescale (permanence) of the effects have been considered, as well as the anticipated risk and uncertainty of the effects.

A summary of the identified potential effects and magnitude of effects assignments are provided in Table 7.1.

While there is a level of confidence that the potential vibration and dewatering impacts on frogs will be very low (possibly negligible) (i.e., a slight change from existing baseline condition/ negligible effect on the known frog population or range; Roper-Lindsay *et al*. 2008), it is acknowledged that some uncertainty remains regarding the scale and magnitude of possible outcomes for frogs. Furthermore, a zero-risk assumption is not supported by the available evidence. Accordingly, a precautionary approach has been taken when assigning magnitude of effect—assuming an exacerbated scenario—, whereby vibration and dewatering effects may result in potential indirect effects (though not direct mortality) on breeding success, movement, and/ or predation vulnerability.

7.2.1 Distribution and abundance of frogs inside the potentially affected area

Historical records and more recent surveys demonstrate that populations of Archey's and Hochstetter's frog occupy the forested habitats above the proposed Wharekirauponga Underground Mine site in Wharekirauponga catchment.

Available data shows that Archey's frog populations are densest in undisturbed native forests at mid to high altitudes (>400 m a.s.l.) throughout the Coromandel. In contrast, the area expected to be impacted by the Wharekirauponga Underground Mine, offers lower-quality habitat for Archey's frog, with altitudes ranging from 90 to 330 m a.s.l., and half the area consisting of historically disturbed and now regenerating forest. Indeed, the Wharekirauponga Underground Mine's affected area footprint represents only 0.61% of Archey's frogs inferred 52,000 ha distribution range in the Coromandel (Lloyd 2025a). If frog densities are similar across the entire range, about 0.61% of the population would reside within the vibration footprint. However, the actual proportion is likely much lower due to the poorer habitat quality in the footprint area. In terms of the size of the population that occupies the 315 ha area of forest above the Wharekirauponga Underground Mine, it is estimated to range between 48,888 and 152,774 adult frogs (61,406–278,785 for all age frogs). This represents a small proportion of the likely very large population of adult Archey's frogs occurring in the Coromandel Range (Lloyd 2025a).

Hochstetter's frogs are common in seepages, creeks, and streams in the Wharekirauponga catchment, and were also found in the lower elevation, wider, and faster flowing streams contrary to previously thought (Boffa Miskell 2020). When examining the detection probability and abundance of Hochstetter's frogs inside versus outside the area affected by the Wharekirauponga Underground Mine, the data indicates that frog encounter rates and frog abundance were significantly lower inside the affected Edmonds sub-catchment compared to areas outside of the affected area (Lloyd 2025b). Furthermore, a lower proportion of juvenile frogs and a higher proportion of mature female frogs were found in the affected area compared to outside the affected area. This may suggest an aging population of frogs, with relatively low juvenile recruitment, in the affected area compared to outside.

The estimated number of Hochstetter's frogs occupying the 12.1 km length of stream in the affected Edmonds sub-catchment ranges between 238 and 1,597 frogs (i.e., density of 0.4–2.6 frogs/ 20 m length of stream) (Lloyd 2025b). These data may suggest that the Hochstetter's frog populations outside the affected area may be faring better than those inside the affected area, though the data is limited.

Overall, the Archey's and Hochstetter's frog populations in the affected Wharekirauponga catchment are largely representative of the wider Coromandel populations in terms of distribution and abundance. However, the presence of lower-quality regenerating forest, which covers approximately half of the affected area, along with possible evidence of an aging population of Hochstetter's frogs, suggests that the populations within the impacted area may be less robust compared to those in the surrounding landscape.

7.2.2 Potential effects of vibration on frogs

The role of anthropogenic substrate vibrations in disrupting animal behaviour is poorly understood and the field is largely under researched. Theoretically, Leiopelmatid frogs do have the anatomical apparatus to detect vibration and the influence of extraneous vibration stimuli on some of the Archey's frogs' more sensitive behaviours such as male egg-brooding remains a possibility. However, to date there is no evidence to verify vibration sensation or perception in leiopelmatid frogs, let alone the positive or negative responses of these frogs to natural or anthropogenic generated vibrations.

The modelled vibration contours for the Wharekirauponga Underground Mine show levels of vibration like those experienced during the historical Golden Cross mining activities. Blast vibrations typically <5 mm/s and infrequently up 10 mm/s were experienced in the areas immediately surrounding Golden Cross Mine, where abundant Archey's and Hochstetter's frog populations were present over the life of the mine (Lane 2021; Heilig & Partners 2024).

In Archey's frog, the high level of investment in egg care by males does suggest that this species can tolerate some level of disturbance and the persistence of both Archey's and Hochstetter's frog populations in the immediate vicinity of the mining operations at Golden Cross suggests both species can tolerate some levels of vibration despite differences in biology and ecology. Indeed, the Golden Cross vibration modelling provides the best circumstantial evidence that Leiopelmatid frogs can tolerate blast vibrations (i.e., between 2–10 mm/s tolerated by Hochstetter's frog and 2 mm/s, maybe up to 4 mm/s, tolerated by Archey's frog). Nevertheless, it is important to recognise that the Golden Cross data does not provide evidence of a vibration threshold (both in terms of vibration acceleration and duration) above which a response that is meaningful in an ecological sense could be expected.
Vibrations from the proposed mine will occur intermittently during an eleven-year period and only be noticeable within a 315 ha area of forest, which represents 0.61% of the Archey's frog Coromandel range (Lloyd 2025a) and even less of the Hochstetter's frog Coromandel range.

7.2.3 Potential effects of dewatering on frogs

Dewatering as part of the Wharekirauponga Underground Mine could potentially impact frog populations if changes to stream or forest characteristics are realised. Any potential impacts on surface water through baseflow losses from streams would not be the same for Archey's and Hochstetter's frogs because of their different ecologies and habitat preferences (i.e., Archey's being terrestrial and Hochstetter's semi-aquatic).

Away from streams, the groundwater modelling predicts that there will be minor or negligible impacts of mine dewatering on groundwater in the shallow aquifers (WWLA 2025a, b). Because the ground water supply to the forest vegetation in the Wharekirauponga catchment that supports Archey's frog populations is not expected to be influenced by mine dewatering, no adverse impacts on terrestrial Archey's frogs nor their habitat are anticipated.

In some streams, surface water baseflows have the potential to temporarily decrease due to deep groundwater extraction for mine dewatering (WWLA 2025a, b). Hochstetter's frogs inhabiting the edges of these streams may experience reductions in the 7-day MALF ranging from 2% to 13%, along with decreases in wetted width of 0–5% across affected sub-catchments during low flow. These effects would be temporary (during mining) and would occur only during periods of lowest flow, primarily impacting areas directly above the Wharekirauponga Underground Mine and downstream (GHD 2025; WWLA 2025b).

Although reductions in flow and wetted width may be noticeable in the most affected sub-catchments, such as Edmonds and Thompson streams, the ecological impacts on the aquatic system are likely to be minor, if not negligible (Boffa Miskell 2024). Even under the unlikely worst-case scenario predicted by groundwater and surface water models, the change in suitable instream habitat for aquatic invertebrates (potential prey for Hochstetter's frog) relative to the median flow would be minimal (less than 6%) when comparing pre-mining conditions with the predicted post-mining situation (NIWA 2024). This minor reduction is unlikely to alter aquatic invertebrate diversity and abundance (Boffa Miskell 2024), and therefore, not affect aquatic food availability for frogs. Hochstetter's frogs are much more reliant on terrestrial (cf. aquatic) invertebrates for food (Stephenson & Stephenson 1957; Sharell 1966; Kane 1980; Chapman & Alexander 2006; Nájera-Hillman *et al*. 2009a; Shaw *et al*. 2012) and any potential alterations to aquatic invertebrate habitat as a result of mine dewatering are not expected to have measurable effects on Hochstetter's frog food availability. Similarly, any small changes to instream habitat for aquatic invertebrates would not have any reaching effects on Archey's frog populations in the surrounding forests because the frogs feed exclusively on terrestrial invertebrates.

Hochstetter's frogs, which are mobile and adapted to living on the banks of dynamic streams with naturally fluctuating water levels, are unlikely to be adversely affected by any small, predicted reductions in flow, wetted width, and instream habitat. The relatively wide streamside margins they inhabit, along with their ability to freely move to more favourable conditions along a stream, suggest they are likely to be unaffected by any minor reductions in baseflow.

Hydrological assessments conclude that most springs, and therefore spring-fed seeps, springbrooks, and small-order streams, will not be impacted by the proposed mine dewatering, as they are fed by shallow water movement sourced from rainfall (WWLA 2025b). Therefore, Hochstetter's frog populations occupying these habitats will not be impacted by the mine dewatering.

The presence and abundance of egg-laying sites and shallow pools necessary to support tadpoles through their development are not expected to reduce as a result baseflow reductions because the predicted reductions to flow and wetted width are so minor. Indeed, in streams with shallow sloping banks and accumulations of rocks/ boulders and leaf litter, lowering of the waterline (reduced wetted width) due to lower flow could plausibly result in additional areas of shallow, pooled or slow flowing water, creating further suitable breeding habitat for Hochstetter's frog.

Table 7.2. Summary of the ecological value and magnitude of effects assignments for native frogs occupying the streams and forests above the proposed Wharekirauponga Underground Mine.

Ecological attribute	Ecological value	Potential effect	Magnitude of effect
Archey's & Hochstetter's frogs	High	**Impacts on frog distribution & abundance** • The Wharekirauponga Underground Mine's ZOI covers a very small proportion of the total area occupied by native frogs in Wharekirauponga catchment and the Coromandel Peninsula.	Low
		Vibration Blast vibrations could potentially cause heightened stress, avoidance behaviours, reduced/ failed reproductive output, and/ or changes in species distribution and species composition. However, measurable effects on frogs are considered unlikely because: • Vibration footprints cover a small proportion of the total area occupied by native frogs in Wharekirauponga and the Coromandel. • Vibrations will be intermittent and are at levels unlikely to result in biological responses that negatively impact frogs and their reproduction, though some uncertainty remains. • Frog populations (both Archey's and Hochstetter's frog) persisted in the vicinity of the historical Golden Cross mine, where similar vibrations from blasts would have been experienced. Some uncertainty remains surrounding frog responses to vibration levels >2 mm/s.	Low
		Dewatering Potential drainage of the shallow groundwater system (groundwater drawdown) could reduce surface water discharges to streams and have a range of ecological effects, some of which could impact frogs (especially stream dwelling Hochstetter's frogs). However, measurable effects on frogs are considered unlikely because: • Reductions in flow and wetted width are unlikely to negatively impact semi-aquatic Hochstetter's frog habitat quantity or quality (i.e., food resources, refuges, breeding habitat) in lower stream catchments, and would not affect higher order catchments where most of the Hochstetter's frog population occurs. • Potential dewatering will have no impact on terrestrial Archey's frogs as their habitat is maintained by surface water, which is not expected to be affected by the mining activities. • Groundwater level recovery expected. E.g., 9% recovery 10 years following cessation of pumping, and full recovery at 20–30 years. Groundwater recovery would occur within the lifespan of a Leiopelmatid frog.	Low

7.3 LEVEL OF EFFECT

The level of effect was assessed using the risk matrix approach that considers ecological value(s) and magnitude of effect(s), as per Table 10 of the EIANZ guidance (Appendix A). Level of effect was initially assessed before measures to avoid, remedy, or mitigate potential adverse effects were applied (Table 7.2). Recognising a level of uncertainty exists surrounding the scale and magnitude of possible outcomes for native frogs, a project-wide mitigation package has been proposed to manage the potential for residual adverse effects associated with the Wharekirauponga Underground Mine.

An outline of the proposed mitigation package for native frogs is provided by RMA Ecology (2025) and detailed further in other technical reports (Boffa Miskell 2025a, b), but in general, the package will include:

1. Mitigation – intensive pest control within 314 ha of the WUG surface footprint (where surface vibrations >2 mm/ sec are expected) to deliver benefits specifically for Archey's frogs and associated benefits for Hochstetter's frogs;
2. Offset – intensive pest control within 318 ha of habitat for Archey's frog to the east and west of WUG (these are areas of Archey's frog habitat that are superior to habitat within most of the WUG footprint; associated benefits are anticipated for Hochstetter's frogs); and
3. Compensation – in the form of financial support for researchers to undertake investigative work within the WUG and wider frog enhancement areas to assess efficacy of pest control regimes for frog recovery, and surveys of the broader Coromandel Peninsula to better understand the distribution and habitat preferences of Archey's frogs.

The level of effect was then assessed after the application of the measures to reduce potential adverse effects listed above, and this is also presented in Table 7.3.

It is also important to highlight that OGNZL's technical experts consider that the management response proposed for native frogs (as per RMA Ecology 2025) will provide a demonstrable net benefit for these species (RMA Ecology 2025; Boffa Miskell 2025b and references sited with), and as such the (low) overall level of effect on native frogs is likely conservative.

Table 7.3. Level of effect before and after mitigation measures.

Ecological attribute	Ecological value	Potential effect	Magnitude of effect	Level of effect (before mitigation)	Level of effect (after mitigation)
Archey's & Hochstetter's frog	High	Distribution & abundance	Low	Moderate	Very low
		Vibration	Low	Moderate	Low (acknowledging uncertainty of effects above 2 mm/s vibration)
		Dewatering	Low	Moderate	Very low

8 SUMMARY OF POTENTIAL MINING EFFECTS ON LEIOPELMATID FROGS

Based on the information presented in this report, it is considered highly unlikely that measurable adverse effects on Leiopelmatid frogs inhabiting the forests and stream habitats above the Wharekirauponga Underground Mine would result from mine-associated blast vibrations or dewatering. While the potential overall level of effect is considered low, some uncertainty remains regarding the scale and magnitude of possible outcomes, and a zero-risk assumption is not supported by the available evidence.

As a precautionary measure, OGNZL has proposed a comprehensive habitat enhancement programme across the project area and its surroundings (including areas of high value frog habitat) to address uncertainties regarding potential effects on native frogs. This habitat enhancement programme will include elements of mitigation (i.e., intensive pest control within 314 ha of the WUG surface footprint, offset (i.e., intensive pest control within 318 ha of habitat for native frogs to the east and west of WUG), and compensation (i.e., financial support for researcher programmes). The enhancement programme will also address other potential impacts on frogs—such as those associated with light, noise, water quality, air pollution, and biotic factors (e.g., vegetation changes)—that have been identified and assessed in detail by other experts (Boffa Miskell 2025a). Overall, it is considered that the management response proposed for native frogs (see RMA Ecology 2025) will provide a demonstrable net benefit for both Archey's and Hochstetter's frogs (RMA Ecology 2025; Boffa Miskell 2025b).

9 ONGOING MONITORING

It is recommended that ongoing monitoring of activities such as blasting, dewatering, and potential affected biological communities be carried out over the life of the mine as good practice. Data collected from rigorous monitoring will help validate the expected project outcomes for frogs.

9.1 VIBRATION MONITORING WUG

Vibration monitoring for blasting will be carried out over the life of the Wharekirauponga Underground Mine. A description of the proposed monitoring programme is provided by Heilig & Partners (2024) and further details will be outlined in a Vibration Management Plan that will be developed to guide actions around monitoring vibration levels, including comparing vibrations to permissible criteria, adaptive modelling, and adjusting monitoring site locations to achieve accurate modelling of surface vibration levels.

9.2 FROG MONITORING

It is recommended that a monitoring programme for both Archey's and Hochstetter's frogs be established and implemented following a Before-After Control-Impact (BACI) design. The monitoring programmes should aim to measure frog occupancy and/ or abundance both within the Wharekirauponga catchment and outside ('control' areas) prior to, during, and post-mining activities associated with the Wharekirauponga Underground Mine. The monitoring programmes should be designed by a biometrician(s) in consultation with a herpetologist(s) to ensure the programme can be feasibly implemented in the field and has statistical rigour.

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12 APPENDICES

12.1 APPENDIX A. EIANZ KEY TABLES FOR ASSESSING LEVEL OF EFFECT.

Table 5 Factors to consider in assigning value to terrestrial species for EcIA

Determining factors	
Nationally Threatened species, found in the ZOI either permanently or seasonally	Very High
Species listed as At Risk – Declining, found in the ZOI, either permanently or seasonally	High
Species listed as any other category of At Risk, found in the ZOI either permanently or seasonally	Moderate
Locally (ED) uncommon or distinctive species	Moderate
Nationally and locally common indigenous species	Low
Exotic species, including pests, species having recreational value	Negligible

Table 6. Scoring for sites or areas combining values for four matters in Table 4.

Value	Description
Very High	Area rates High for 3 or all of the four assessment matters listed in **Table 4**. Likely to be nationally important and recognised as such.
High	Area rates High for 2 of the assessment matters, Moderate and Low for the remainder, or Area rates High for 1 of the assessment maters, Moderate for the remainder. Likely to be regionally important and recognised as such.
Moderate	Area rates High for one matter, Moderate and Low for the remainder, or Area rates Moderate for 2 or more assessment matters Low or Very Low for the remainder Likely to be important at the level of the Ecological District.
Low	Area rates Low or Very Low for majority of assessment matters and Moderate for one. Limited ecological value other than as local habitat for tolerant native species.
Negligible	Area rates Very Low for 3 matters and Moderate, Low or Very Low for remainder.

Table 8. Criteria for describing magnitude of effect (Adapted from Regini (2000) and Boffa Miskell (2011))

Magnitude	Description
Very high	Total loss of, or very major alteration to, key elements/features/ of the existing baseline conditions, such that the post-development character, composition and/or attributes will be fundamentally changed and may be lost from the site altogether; AND/OR Loss of a very high proportion of the known population or range of the element/feature
High	Major loss or major alteration to key elements/features of the existing baseline conditions such that the post-development character, composition and/or attributes will be fundamentally changed; AND/OR Loss of a high proportion of the known population or range of the element/feature
Moderate	Loss or alteration to one or more key elements/features of the existing baseline conditions, such that the post-development character, composition and/or attributes will be partially changed; AND/OR Loss of a moderate proportion of the known population or range of the element/feature
Low	Minor shift away from existing baseline conditions. Change arising from the loss/alteration will be discernible, but underlying character, composition and/or attributes of the existing baseline condition will be similar to pre-development circumstances or patterns; AND/OR Having a minor effect on the known population or range of the element/feature
Negligible	Very slight change from the existing baseline condition. Change barely distinguishable, approximating to the 'no change' situation; AND/OR Having negligible effect on the known population or range of the element/feature

Table 10. Criteria for describing level of effects (Adapted from Regini (2000) and Boffa Miskell (2011))

Ecological Value ▶ Magnitude ▼	Very high	High	Moderate	Low	Negligible
Very high	Very high	Very high	High	Moderate	Low
High	Very high	Very high	Moderate	Low	Very low
Moderate	High	High	Moderate	Low	Very low
Low	Moderate	Low	Low	Very low	Very low
Negligible	Low	Very Low	Very low	Very low	Very low
Positive	Net gain	Net gain	Net gain	Net gain	Net gain

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