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Integrating Indigenous Community-Developed Consequence Functions into Conventional Inundation Risk Modelling: An Aotearoa New Zealand Case Study

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Abstract

Quantitative multi-hazard risk modelling platforms typically compute loss through economic depth-damage functions that overlook the cultural, emotional, and ecological dimensions of risk experienced by Indigenous communities. This paper presents a methodology for codifying qualitative, iwi-led (tribal community) consequence functions into formats suited for integration within the RiskScape multi-hazard risk modelling platform, demonstrated through a case study with Rangitāne o Wairau in the southern Marlborough district of Aotearoa New Zealand. Building on thematic consequence tables co-developed through semi-structured interviews with Rangitāne whānau (extended family) members [1], we describe the four-stage process of translating qualitative mātauranga Māori (Māori knowledge systems) into quantitative depth-impact relationships across four domains: Cultural Disruption, Economic Loss, Emotional Stress, and Ecological Damage. The codified functions were applied within a RiskScape pipeline to assess taonga (treasured cultural heritage) exposure under a Mw 9.0 Hikurangi subduction zone tsunami scenario, using co-developed exposure layers representing culturally significant land types. Results reveal that 86.8% of Beach/Bay taonga and 98.3% of Beach/Bay elements under Emotional Stress sustain Severe impacts, underscoring the extreme cultural weight Rangitāne place on these ancestral landscapes. We discuss the methodological considerations, limitations, and scalability of the approach, and argue that iwi-led consequence functions provide a replicable framework for embedding Indigenous knowledge systems within national-standard hazard risk assessment tools.

1. Introduction

Multi-hazard risk assessment frameworks are central to disaster risk reduction planning in Aotearoa New Zealand and globally. Platforms such as RiskScape [2] combine geospatial hazard layers, exposure data, and vulnerability or consequence functions to quantify potential losses under defined scenarios. However, the consequence functions embedded within these tools are overwhelmingly economic in design, expressing loss as a monetary proportion of asset replacement value as a function of hazard intensity (e.g., flood depth). For Indigenous communities such as Māori, this framing systematically omits the dimensions of risk that matter most: the disruption of cultural continuity, the emotional and spiritual burden of losing ancestral connections to place, the degradation of mahinga kai (traditional food-gathering places and practices) and natural ecosystems, and the erosion of intergenerational knowledge systems [3,4].

Recent scholarship has called for the meaningful integration of mātauranga Māori into hazard and climate risk governance (e.g., [5–7]). However, the translation of qualitative Indigenous knowledge into quantitative formats compatible with operational risk modelling tools remains an open methodological challenge. While Mckenzie Sheat et al. [1] present the qualitative foundation for such integration – identifying five thematic domains through which Rangitāne o Wairau whānau experience and define inundation risk – the question of how these qualitative insights can be codified into consequence functions suitable for computational risk models has not yet been addressed in the literature.

This paper aims to address that gap. Drawing on the thematic consequence tables presented in Mckenzie Sheat et al. [1], we describe the process of translating qualitative, iwi-led consequence categories into weighted depth-impact relationships, codifying them as a consequence function pipeline within the RiskScape platform, and applying them to assess taonga exposure under tsunami and sea-level rise (SLR) scenarios in the southern Marlborough district (Fig. 1). The Rangitāne o Wairau case study serves as a demonstration of the methodology, which is designed to be transferable to other iwi, rohe (tribal territory), and hazard contexts.

The paper makes three contributions. First, it presents a structured, four-stage workflow for the qualitative-to-quantitative translation of Indigenous consequence knowledge. Second, it provides the first documented integration of iwi-led consequence functions into a national-standard multi-hazard risk modelling platform. Third, it produces quantitative exposure outputs that demonstrate how culturally defined risk metrics alter the interpretation of hazard scenarios relative to conventional economic-only assessments.

2. Study area and context

Te Pokohiwi o Kupe (Wairau Bar) is a site of national significance in the southern Marlborough district, dating to c. 1280 AD and described by Rangitāne o Wairau as a cornerstone of their identity and whakapapa (ancestral genealogy) [8,9] (see Fig. 1). The site is located on a low-lying gravel bar at the mouth of the Wairau River, exposed to tsunami from the Hikurangi subduction zone and Wairarapa-Nicholson fault, as well as progressive SLR and coastal erosion. Williams et al. [10] demonstrated that SLR is currently outpacing the natural morphological growth of the Boulder Bank, with modelling indicating up to 75% of Te Pokohiwi o Kupe could be inundated by 2100 under a 1 m SLR scenario.

For Rangitāne, the degradation of wāhi tapu (sacred site/s), disruption of mahinga kai, and erosion of urupā (burial ground/s) represent losses that extend well beyond structural or economic categories. The qualitative dimensions of these risks – documented through interviews with 19 Rangitāne whānau members – are presented in Mckenzie Sheat et al. [1], who identify five interlinking themes: Relationship with Place, Environmental Change, Impacts of Hazards, Mitigating and Living with Hazards, and Aspirations for the Future. These themes were consolidated into structured consequence tables documenting hazard types, observed impacts, consequences for Rangitāne, and their cultural significance. The present paper builds directly on these tables, describing their translation into quantitative consequence functions.

3. Methodology

The methodology comprises four interconnected components: (a) hazard modelling; (b) exposure layer development; (c) consequence function codification; and (d) risk model integration and application. Components (a) and (b) generate the input data; component (c) is the core methodological contribution of this paper; and component (d) demonstrates the end-to-end pipeline. All work was conducted under a

co-developed Mātauranga Māori Plan governing data sovereignty [1], with Rangitāne o Wairau retaining authority over all mātauranga shared or generated.

3.1. Hazard modelling

Two-dimensional tsunami inundation models were developed using the BG-Flood numerical software suite, which solves the non-linear shallow water equations on an adaptive computational grid [12]. The model domain covered Te Koko-o-Kupe/Cloudy Bay, Clifford Bay, and the Wairau Plains, with adaptive grid resolution ranging from approximately 100 m offshore to 10 m in nearshore areas of interest (Fig. 2). Key input datasets included: the Marlborough hydraulically conditioned Light Detection and Ranging (LiDAR) digital elevation model (DEM); Earth Sciences New Zealand offshore bathymetry; co-seismic vertical displacements from complex fault models [13]; and the New Zealand National Probabilistic Tsunami Hazard Model [14] (Table 1).

Table 1
Summary of existing baseline datasets versus new outputs developed through this project

Component	Existing (pre-project)	New (this project)
LiDAR DEM	Marlborough District Council hydraulically conditioned LiDAR	Integrated into BG-Flood adaptive grid
Offshore bathymetry	Earth Sciences New Zealand national bathymetry dataset	Merged with LiDAR for coastal model domain
Tsunami scenarios	1D Level-2 attenuation zones [15]	2D BG-Flood simulations for 5 fault scenarios × SLR increments
SLR inundation	Static inundation SLR models (via Deep South National Challenge programme)	Static inundation SLR models (Te Pokohiwi o Kupe area) – obtained from [10]
Exposure layers	No cultural asset layer existed	Co-developed taonga exposure layer with Rangitāne o Wairau whānau
Consequence functions	Standard RiskScape economic depth-damage curves	Iwi-led 4-domain consequence functions

Tsunami scenarios represented the 2,500-year return period (84th percentile) maximum credible events for the Hikurangi subduction zone (Mw 9.0) and the Wairarapa-Nicholson fault (Mw 8.6), as well as 500-year events (Mw 8.5 and Mw 8.1). Model outputs comprised geospatial maps of maximum inundation depth, velocity, and energy flux in netCDF and GeoTIFF formats. Static SLR scenarios used a bathtub approach with hydraulic connectivity analysis at increments from 0.1 m to 2.0 m, aligned with Intergovernmental Panel on Climate Change (IPCC) Shared Socioeconomic Pathways (SSP) projections [16].

3.2. Exposure layer development

A culturally informed exposure layer was co-developed with Rangitāne o Wairau whānau, digitised at 1 m grid resolution into heritage land area polygons (Fig. 3). Each polygon was attributed with land-type categories (urupā and settlement sites, pā (fortified settlement/s) sites, cropland, vineyard, wetland, river, riverbank, beach/bay) and impact-type classifications (Cultural Disruption, Emotional Stress, Economic Loss, Ecological Damage). This represents the first cultural asset exposure dataset that was an essential prerequisite for applying the iwi-led consequence functions.

3.3. Consequence function

The core methodological contribution of this paper is the four-stage process for translating the qualitative consequence tables presented in Mckenzie Sheat et al. [1] into quantitative consequence functions compatible with the RiskScape platform. The process is summarised in Fig. 4 and described in detail below.

Stage 1 – Qualitative foundation

The starting point is the qualitative data collected through 19 semi-structured interviews and hīkoi (on-site guided walks) with Rangitāne whānau, analysed using NVivo thematic coding and consolidated into five overarching themes [1]. These themes capture the relational, cultural, emotional, ecological, and economic dimensions through which Rangitāne experience and define inundation risk.

Stage 2 – Thematic consequence table structuring: The five themes were refined into structured consequence tables (Tables 1–5 in [1]), each documenting: the hazard type (flooding, erosion, SLR); the observed or anticipated impact; the consequence for Rangitāne; and the cultural significance or whānau response. These tables were co-developed with Rangitāne and validated at a workshop in May 2025.

Stage 3 – Weighted impact scoring: The consequence categories were distilled into four quantifiable impact domains – Cultural Disruption, Economic Loss, Emotional Stress, and Ecological Damage – each representing a distinct dimension of loss identified by Rangitāne as significant. For each domain, weighted values ranging from 0 (no measurable impact) to 1 (total or irreversible disruption) were assigned qualitatively based on the perceived severity and significance of consequences at four flood depth exposure thresholds: ≤0.2 m (Low), > 0.2–0.5 m (Moderate), > 0.5–1.0 m (High), and > 1.0 m (Severe). The scoring followed a structured framework (see Table 2), and was validated by Rangitāne whānau at a hui (community gathering) in May 2025.

Table 2
Weighted iwi-led consequence scores by impact level and flood depth exposure threshold

Flood Depth	Impact Level	Cultural Disruption	Economic Loss	Emotional Stress	Ecological Damage
≤ 0.2 m	Low	0.3	0.1	0.5	0.2
> 0.2–0.5 m	Moderate	0.6	0.4	0.7	0.5
> 0.5–1.0 m	High	0.8	0.6	0.8	0.7
> 1.0 m	Severe	1.0	0.9	1.0	1.0

Stage 4 – Risk model integration

The weighted depth-impact relationships were codified as a consequence function compatible with multi-hazard risk modelling platforms, implemented here within RiskScape (Fig. 5). The function accepts flood depth as input, classifies it into an impact level based on the depth thresholds defined in Stage 3, and returns normalised consequence scores for each of the four domains. The function was linked to the co-developed taonga exposure layer, with each grid cell tagged with Māori land and cultural attributes. The pipeline was implemented in the RiskScape specification language and deployed on the secured Rangitāne RiskScape platform, ensuring data sovereignty is maintained.

A key design principle was that the consequence function should be modular: the depth thresholds, domain weightings, and exposure attributes can be independently adjusted without modifying the pipeline architecture. This supports future refinement by Rangitāne and adaptation to other iwi contexts where different thresholds or additional impact domains may be appropriate.

3.4. Risk model integration and application

The RiskScape platform was used to combine the hazard layers, exposure data, and consequence functions into a quantitative risk modelling pipeline (Fig. 6). The workflow comprised five steps: (1) import of 2D geospatial hazard layers (maximum inundation depth from tsunami and SLR scenarios) as raster inputs; (2) loading of the co-developed taonga exposure layer at 1 m gridded resolution; (3) all-intersections geoprocessing to sample maximum flow depth at each exposure grid cell; (4) application of the iwi-led consequence function to classify impact level and compute weighted scores for each domain; and (5) aggregation of results into event impact tables disaggregated by land type and consequence domain.

4. Results

We present results for the Mw 9.0 Hikurangi subduction zone tsunami scenario at present-day mean high-water springs (MHWS), representing the 2,500-year return period maximum credible event. This

scenario was selected as the benchmark because it produces the most extensive inundation across the taonga exposure area and therefore exercises the full range of the consequence function.

4.1. Inundation extent and depth distribution

The Mw 9.0 Hikurangi scenario produces extensive inundation across the Wairau Plains, with maximum flow depths exceeding 3 m in low-lying coastal areas and 1–2 m across much of the Te Pokohiwi o Kupe heritage area (Fig. 7). The inundation reaches inland approximately 4 km from the coast, affecting agricultural land, wetlands, and river margins in addition to culturally significant sites.

4.2. Taonga exposure by impact level and consequence domain

Figure 8 Stacked bar chart showing percentage of exposed taonga elements by impact level (Low, Moderate, High, Severe) across Ecological Damage, Economic Loss, and Emotional Stress domains for the Mw 9.0 Hikurangi tsunami scenario. Cultural Disruption — the fourth consequence domain — is not presented as a standalone output category because Rangitāne o Wairau conceptualise it as a cross-cutting dimension of loss inherently embedded within the other three domains. Ecological Damage, Economic Loss, and Emotional Stress each represent a distinct expression of cultural disruption and together constitute its full analytical representation within the model

The results reveal several notable patterns (see Table 3). Ecological Damage is dominated by Severe impact across natural land types: Beach/Bay (86.8%), River (79.3%), and Wetland (54.1%). Riverbank (63.8% Severe) and Wetland show a broader distribution across impact levels, reflecting the gradient of inundation depth across these landforms. Urupā and Settlement Sites are a notable exception, showing the highest proportion at High impact (46.9%) with relatively low Severe (5.1%), likely because these sites occupy slightly higher elevations within the exposure area.

Table 3
Summary statistics of taonga exposure by land type and consequence domain for the Mw 9.0 Hikurangi subduction zone tsunami scenario at present-day MHWS (n = 155,594 grid cells). Percentages represent the proportion of exposed elements at each impact level. Mean consequence score is calculated using level midpoints (Low = 0.2, Moderate = 0.45, High = 0.75, Severe = 0.95)

Consequence domain	Land type	n	Low (%)	Mod (%)	High (%)	Severe (%)	Mean score
Ecological Damage	Beach / Bay	74,298	0.3	2.1	10.9	86.8	0.916
	River	16,728	2.4	6.7	11.7	79.3	0.875
	Riverbank	5,744	6.6	13.7	15.9	63.8	0.800
	Urupā & settlement sites	256	17.6	30.5	46.9	5.1	0.572
	Wetland	23,935	4.1	10.7	31.1	54.1	0.803
Economic Loss	Beach / Bay	14,725	0.0	1.7	9.5	88.8	0.922
	Cropland	60	8.3	18.3	28.3	45.0	0.739
	Urupā	26	19.2	42.3	34.6	3.8	0.525
	Vineyard	974	9.9	15.8	23.9	50.4	0.749
Emotional Stress	Beach / Bay	17,599	0.0	0.0	1.7	98.3	0.946
	River	1,242	4.2	20.2	16.6	59.0	0.784
All domains	**All land types**	**155,594**	**1.7**	**4.5**	**14.3**	**79.5**	**0.887**

Economic Loss shows Beach/Bay at 88.8% Severe, while Vineyard (50.4%) and Cropland (45.0%) have a more distributed profile across levels, reflecting the broader spatial extent and elevation range of agricultural land. Urupā sites again display a distinctive profile (42.3% Moderate, 34.6% High), consistent with their elevated but still exposed position.

Emotional Stress is the most extreme domain: Beach/Bay reaches 98.3% Severe, and River 59.0% Severe. These values reflect the high weighting the consequence function assigns to the emotional and spiritual burden of coastal inundation on ancestral landscapes – a dimension of risk entirely absent from conventional economic depth-damage assessments.

5. Discussion

5.1. Methodological considerations

The four-stage codification process presented here addresses a recognised gap in the literature: the translation of qualitative Indigenous knowledge into quantitative formats compatible with operational hazard risk modelling tools. Previous work has established the importance of integrating mātauranga

Māori into disaster risk reduction frameworks [7,17,18], and Mckenzie Sheat et al. [1] demonstrate how qualitative interview data can be structured into thematic consequence tables. The present paper extends this work by providing the codification bridge between qualitative consequence categories and a computational risk modelling pipeline.

A critical design principle was modularity. The consequence function separates the depth classification thresholds, the domain weightings, and the exposure attributes into independently adjustable parameters. This means that if Rangitāne subsequently wish to refine a weighting (e.g., increasing the Cultural Disruption score for shallow inundation based on new mātauranga), the change can be made without re-engineering the pipeline. Similarly, the function architecture can be adopted by another iwi who would supply their own thresholds, weightings, and exposure layer, while retaining the same computational structure.

5.2. Significance of the results

The exposure results under the Mw 9.0 Hikurangi scenario highlight a pattern that would be invisible under conventional economic-only assessment. The Emotional Stress domain consistently produces the highest Severe-impact percentages across all land types, reflecting the consequence function's encoding of Rangitāne's expressed experience that emotional and spiritual loss is the most profound dimension of inundation risk. Conventional depth-damage curves, by definition, cannot represent this dimension. The implication for policy and governance is significant: that is, national catastrophic criteria that rely solely on economic loss metrics will systematically underestimate the severity of hazard impacts on Māori communities (e.g., [19]).

New Zealand New Zealand National Emergency Management Agency (NEMA) representatives who attended the project's March 2026 wānanga (knowledge-sharing workshop) confirmed that current national catastrophic criteria do not adequately capture cultural impacts for Māori, and expressed interest in using the consequence function framework to help inform future criteria development. This suggests a practical pathway for the research to influence national-level hazard governance.

The value of this multi-domain framing becomes most apparent when considered alongside conventional economic-only assessments applied to the same scenario. A standard depth-damage curve for residential property would return a single percentage-of-replacement-value metric – which captures nothing of the cultural disruption, emotional burden, or ecological degradation that Rangitāne identified as most consequential. The four-domain consequence function does not compete with economic assessment, but provides a complementary analytical lens that makes visible dimensions of risk structurally absent from national-standard tools. What matters is not numerical equivalence across different scales, but the categorical shift in what is represented as loss: at any given flood depth, a conventional assessment returns a single economic figure, while the iwi-led function simultaneously surfaces cultural disruption, emotional stress, and ecological damage – dimensions that are not merely unmeasured but unmeasurable within the conventional framework. National catastrophic criteria

grounded solely in economic metrics will systematically understate the severity of hazard impacts for Māori communities – a limitation which this framework is designed to address.

5.3. Limitations

Several limitations should be acknowledged. The consequence functions are based on qualitative weightings derived from interviews with 19 whānau members of a single iwi. While validated through a co-validation hui, the weightings are inherently subjective and context-specific to Rangitāne o Wairau [20]. No sensitivity testing of the weighting values has been undertaken to date. The functions should be understood as a baseline framework rather than a definitive or generalisable set of parameters.

The hazard modelling component has its own limitations: the BG-Flood model does not simulate morphodynamic feedback (erosion or sediment transport during inundation), and the SLR scenarios rely on static superposition onto present-day topography without accounting for future geomorphological adaptation. The 1 m grid resolution of the exposure layer introduces spatial generalisation, and the binary classification of land types may not capture the full complexity of cultural landscape use.

A further limitation is that the consequence function parameters have not yet been validated against observed impacts from a real-world inundation event. The depth-threshold weightings were co-validated with Rangiţāne whānau through structured workshop processes, but it remains to be tested whether these values accurately reflect the severity of consequences experienced following an actual flood or tsunami. Post-event community feedback may confirm the assigned scores, or may indicate that certain thresholds or domain weightings require recalibration. Tracking consequences under real inundation conditions is therefore an important next step before the framework is applied in predictive or decision-making contexts.

5.4. Scalability and transferability

The methodology is designed to be scalable (e.g., Fig. 9). At the March 2026 wānanga, Te Ātiawa representatives identified comparable coastal sites at Waikawa, Tōtaranui, Mārahau, and Motueka as candidates for similar work. The efficiency of roll-out depends on the availability of two components: hazard data (which may already exist from regional council assessments) and cultural exposure layers (which require iwi co-development). Where one component already exists, the marginal cost of the full framework is substantially reduced.

A key enabling factor for scalability is the iwi-to-iwi knowledge transfer model. Rangitāne o Wairau have indicated willingness to share their experience of the co-design process with other Te Tau Ihu (northern South Island region) iwi – not their mātauranga or cultural data (which remain under Rangitāne data sovereignty), but the process: how they approached co-governance, what they learned about working with science tools, and how the outputs have supported their strategic objectives. This peer-to-peer model builds trust more effectively than a researcher-only approach and represents a potentially significant mechanism for national-scale adoption.

6. Conclusions

This paper presents the first documented methodology for codifying iwi-led consequence functions into a national-standard multi-hazard risk modelling platform. Building on the qualitative thematic consequence tables developed by Mckenzie Sheat et al. [1] through co-designed research with Rangitāne o Wairau, we describe a four-stage process – qualitative foundation, thematic structuring, weighted impact scoring, and risk model integration – that translates mātauranga Māori into quantitative depth-impact relationships across four domains: Cultural Disruption, Economic Loss, Emotional Stress, and Ecological Damage.

Application of the codified functions to a Mw 9.0 Hikurangi tsunami scenario demonstrates that culturally defined consequence metrics reveal patterns of risk that are entirely invisible under conventional economic-only assessment. Emotional Stress consistently produces the highest Severe-impact percentages across all land types, reflecting the extreme cultural weight Rangitāne place on the spiritual and emotional dimensions of coastal inundation. These results have direct implications for national hazard governance, particularly for the development of catastrophic criteria that adequately represent Māori risk.

The methodology is designed to be modular, reproducible, and transferable. The separation of depth thresholds, domain weightings, and exposure attributes means the pipeline can be adapted to other iwi, rohe, and hazard contexts without re-engineering. We argue that iwi-led consequence functions provide a scalable, culturally grounded complement to conventional economic depth-damage curves, and offer a practical pathway for embedding Indigenous knowledge systems within operational hazard risk assessment frameworks in Aotearoa New Zealand and internationally.

Declarations

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Conflicts of interest: The authors declare no competing interests.

Ethics approval: This research received ethical approval from the Earth Sciences New Zealand Human Research Ethics Committee and was conducted in accordance with the principles of Te Ara Tika: Guidelines for Māori Research Ethics (Health Research Council of New Zealand, 2010), which govern ethical conduct in research involving Māori participants and communities, including requirements for informed consent, data sovereignty, and culturally safe engagement.

Data availability: The qualitative interview data and cultural exposure layers are held under the governance of Te Rūnanga a Rangitāne o Wairau in accordance with the Mātauranga Māori Plan. The RiskScape consequence function pipeline code is available on the secured Rangitāne RiskScape

platform. Requests for access should be directed to Te Rūnanga a Rangitāne o Wairau. Tsunami hazard model outputs are available from the corresponding author on reasonable request.

Author contributions: SW: conceptualisation, methodology, analysis, visualization, project leadership, writing. CH: co-design, cultural governance, validation, writing. RP: RiskScape integration, risk modelling, data curation. PM: kaupapa Māori (Māori-centred research approach) oversight, formal analysis, cultural governance. JB: GIS analysis, exposure layer development, visualization. CB: hazard modelling, computational methods, visualization. RMS: qualitative data collection, thematic analysis, consequence table development. JH: cultural engagement, formal analysis, mātauranga Māori plan.

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Figures

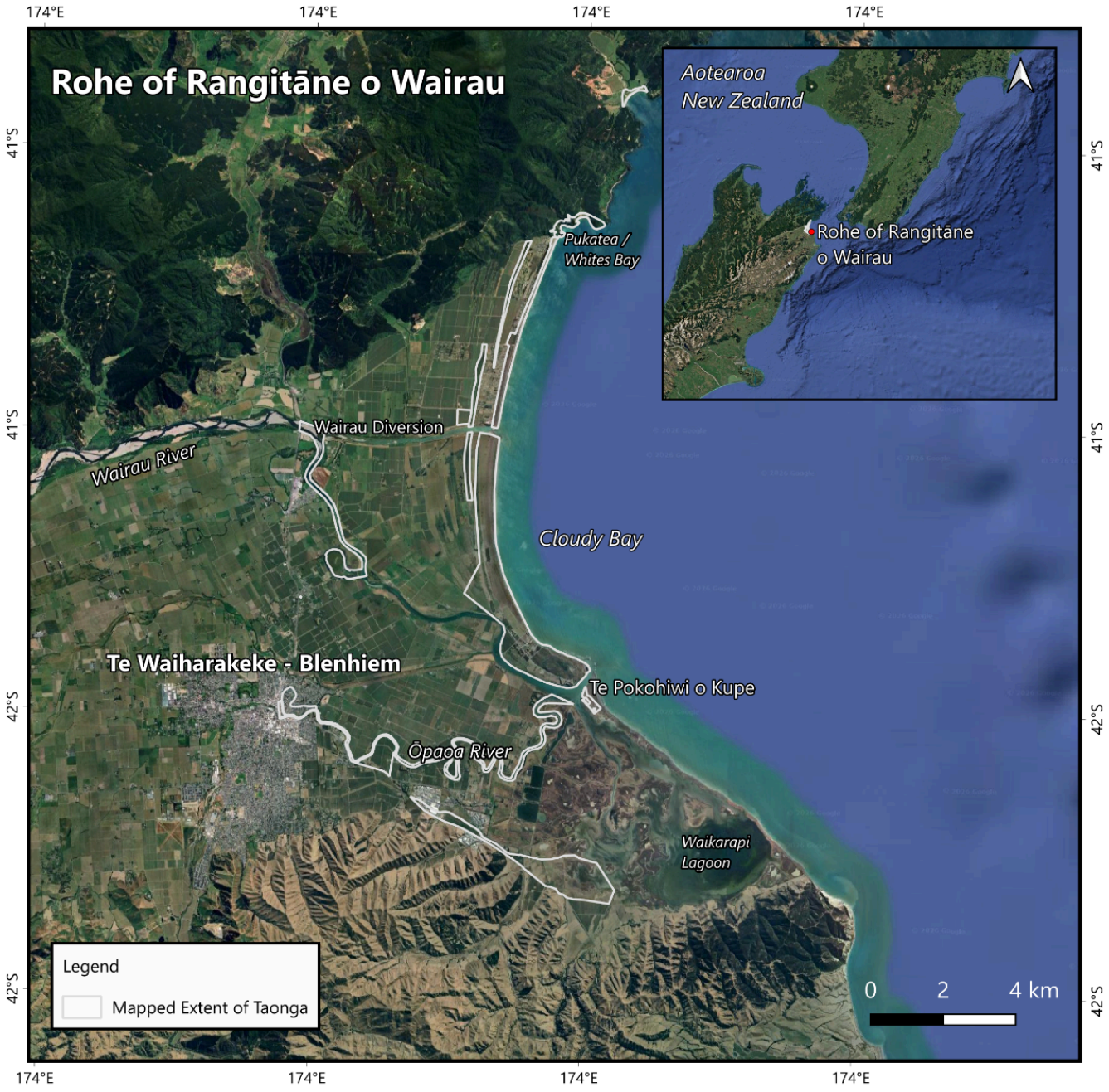


Figure 1

Location map of Te Pokohiwi o Kupe within the rohe of Rangitāne o Wairau, showing the study area extent, key cultural/environmental features, and the taonga exposure layer boundary

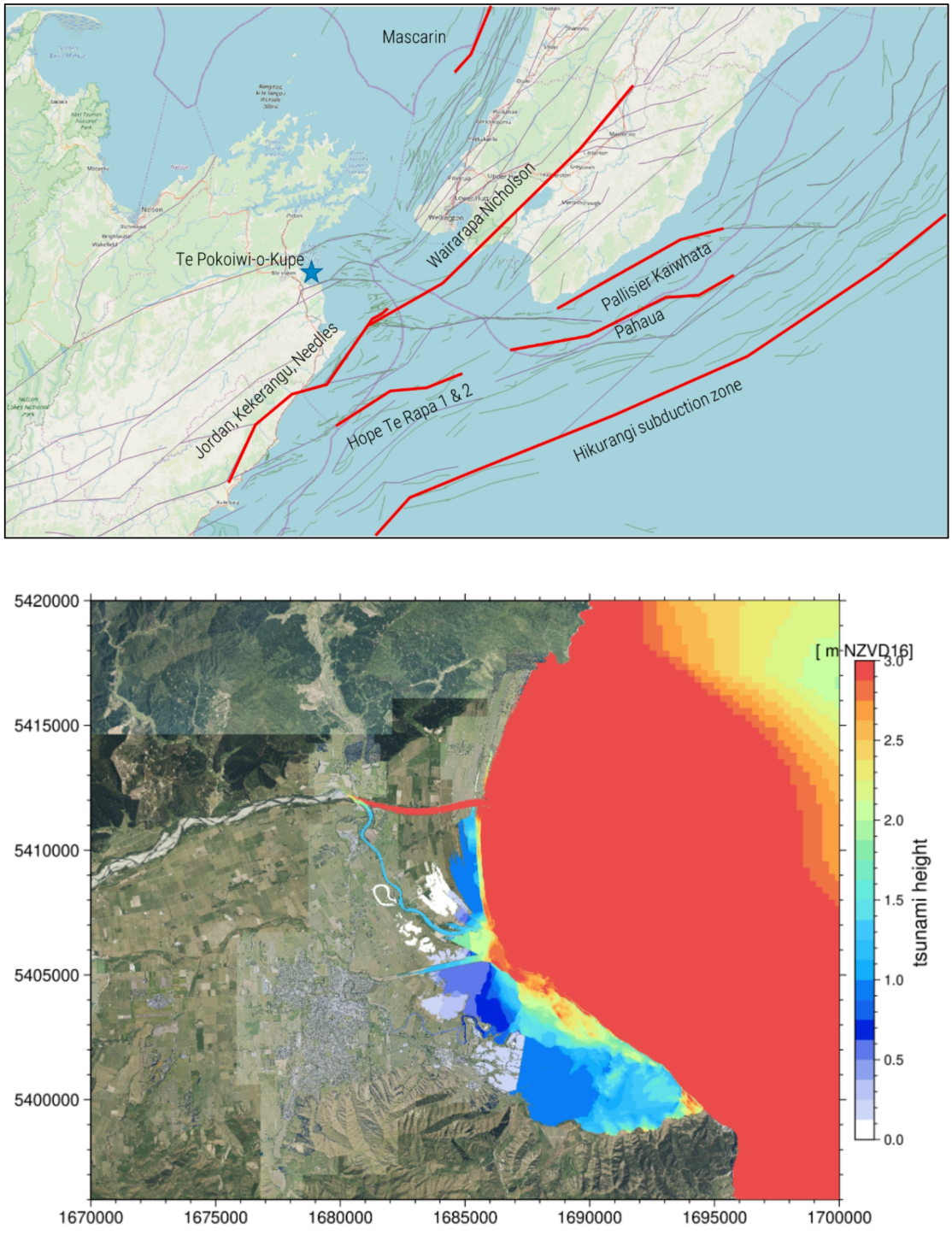


Figure 2

(Top) Regional overview showing the BG-Flood model domain and fault sources; (Bottom) Simulated maximum inundation depth for the Mw 9.0 Hikurangi scenario at present-day sea level across the Wairau Plains and Te Pokohiwi o Kupe

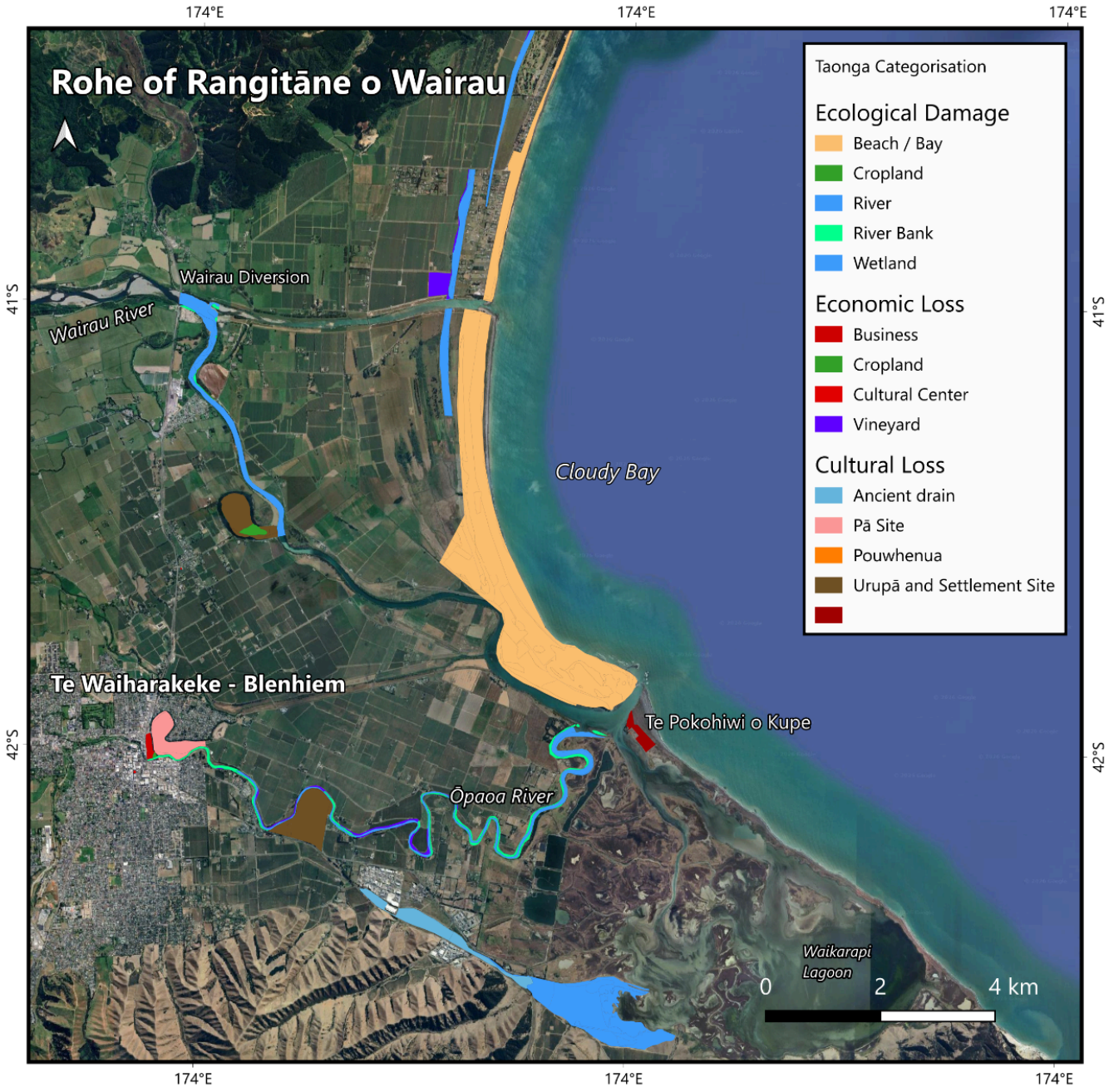


Figure 3

Taonga exposure layer co-developed with Rangitāne o Wairau, showing the spatial distribution of heritage land area polygons by land-type category

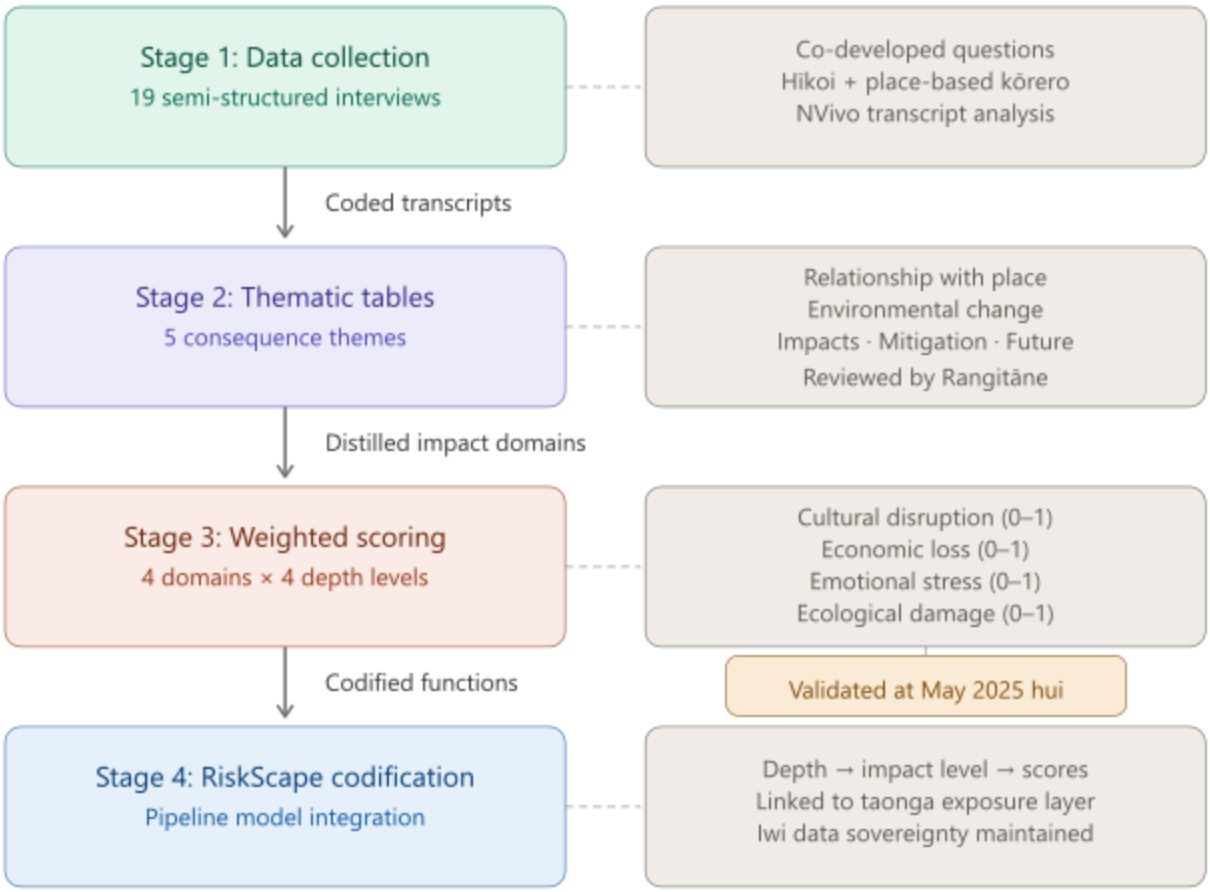


Figure 4

Four-stage workflow from qualitative mātauranga interviews through to quantitative consequence function codification

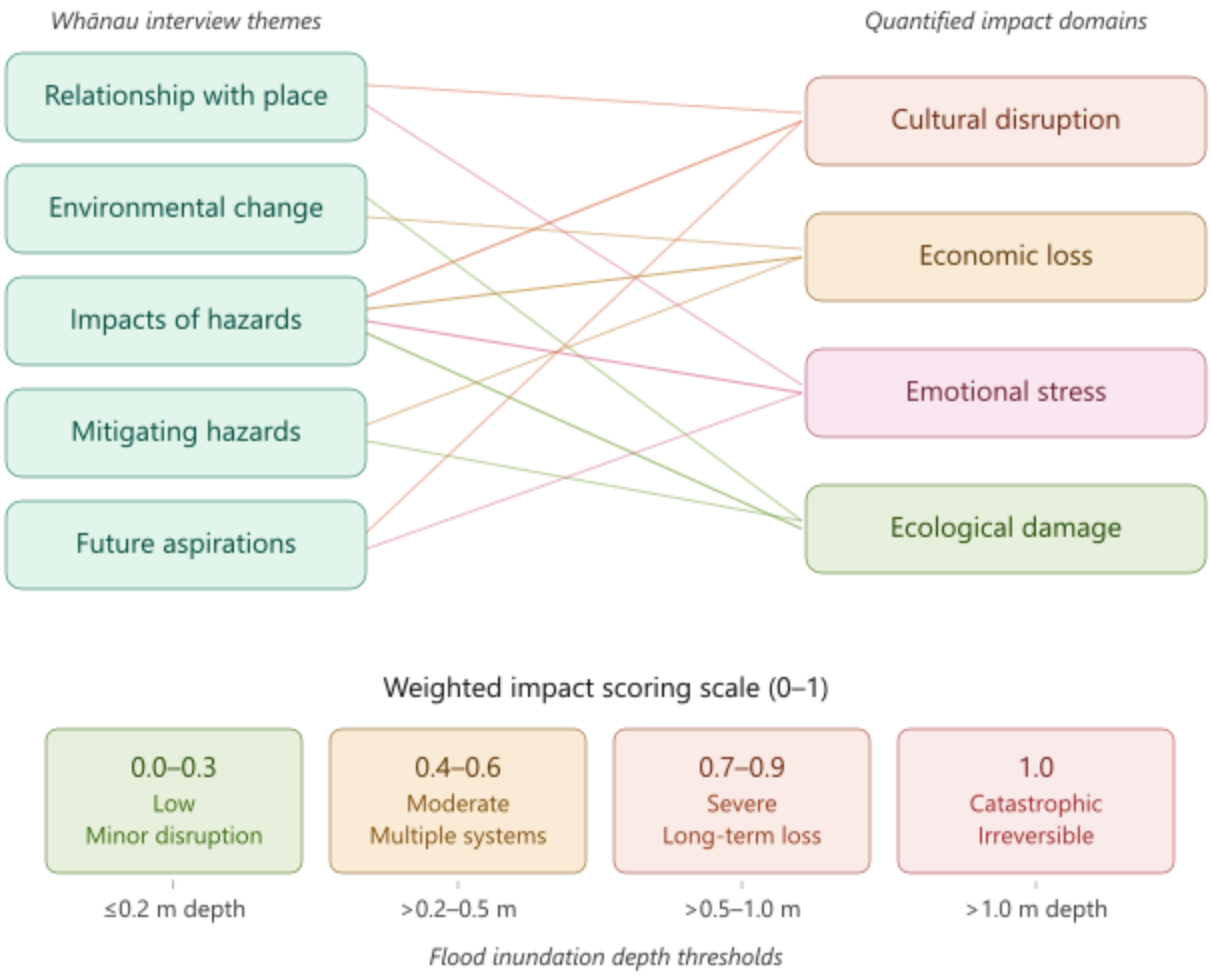


Figure 5

Schematic of the consequence function pipeline showing the input–classification–output structure, including the depth threshold classification, domain score lookup, and output format

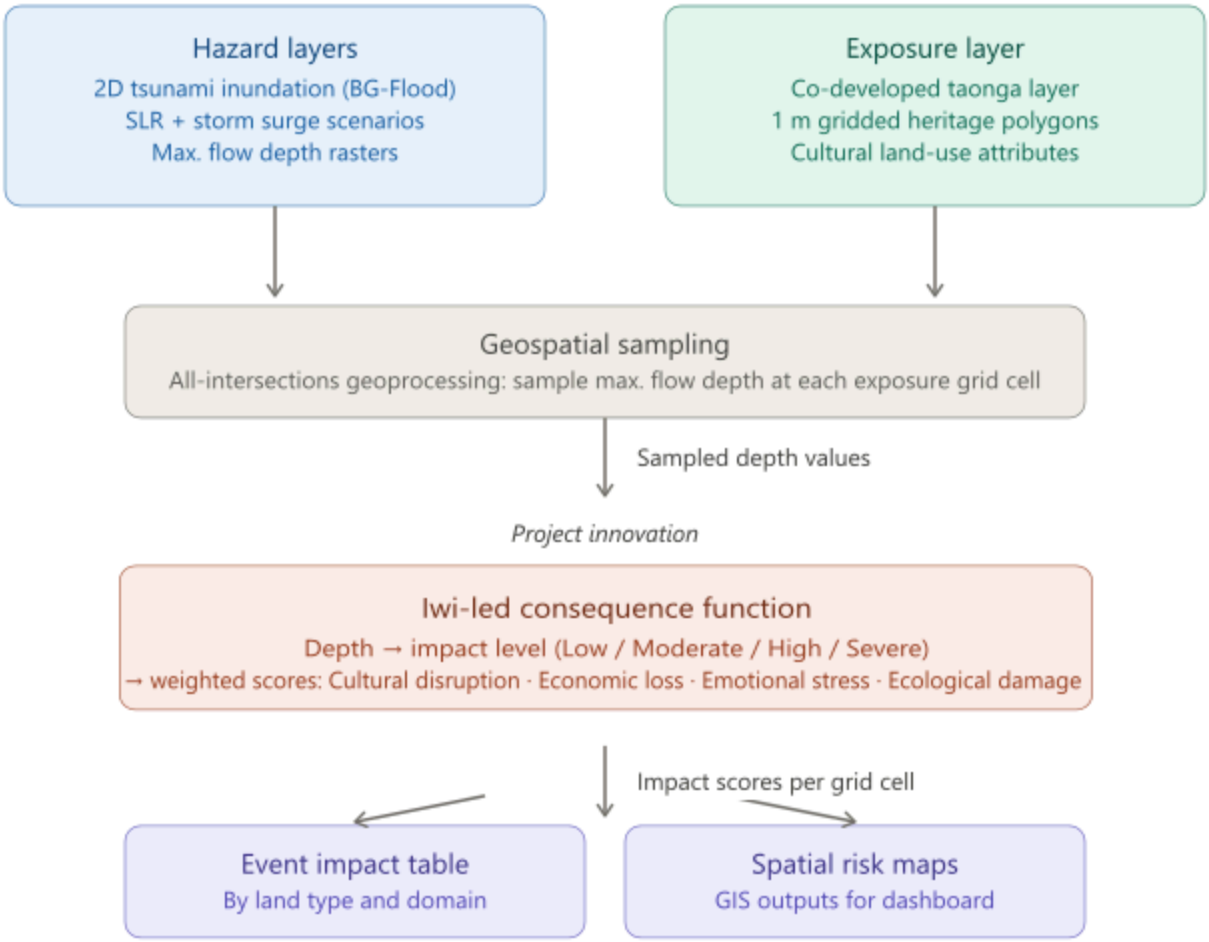


Figure 6

Risk modelling methodology schematic showing data flow from hazard and exposure inputs through geospatial sampling, iwi-led consequence analysis, and output reporting

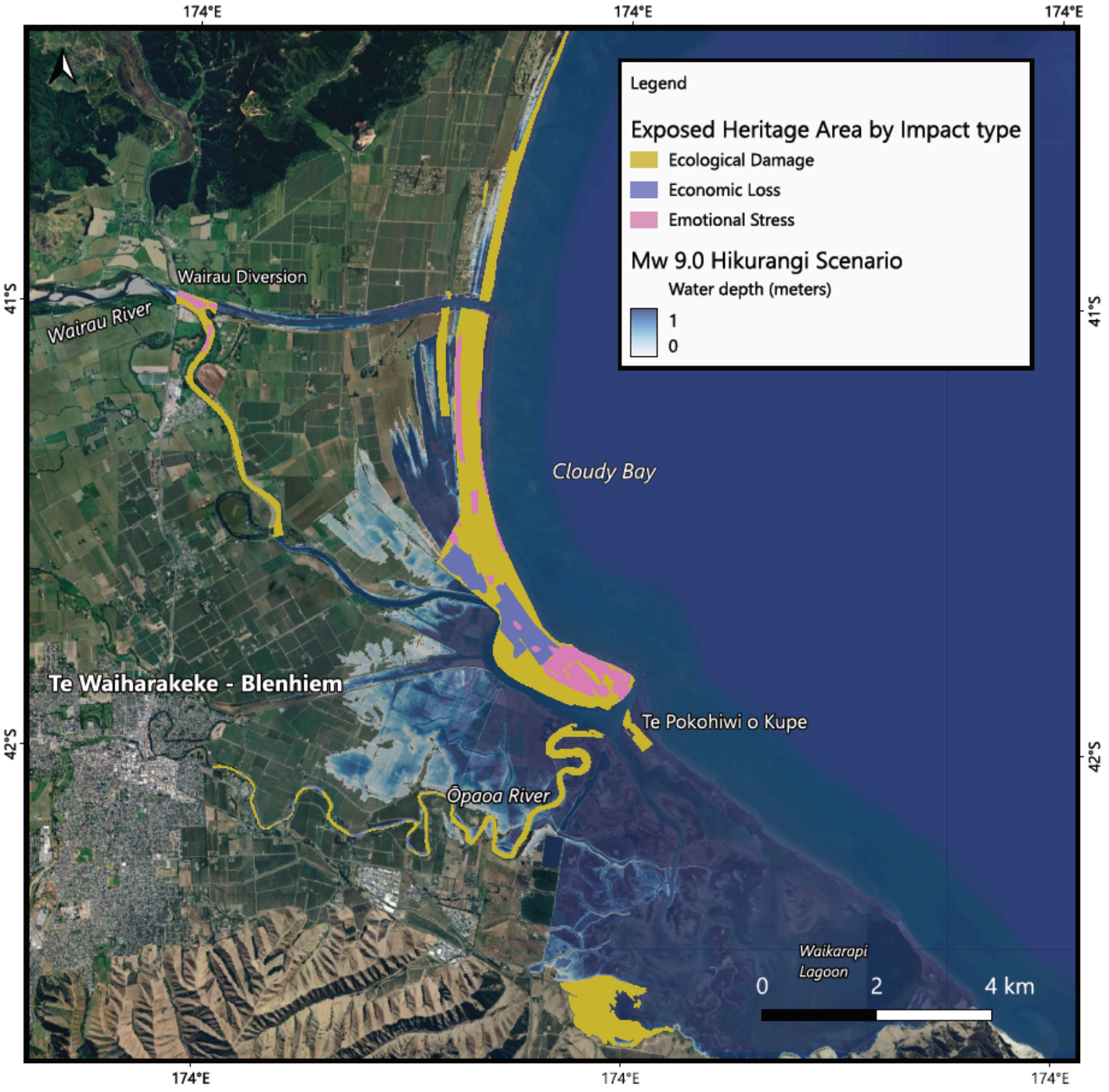


Figure 7

Spatial distribution of maximum inundation depth across the taonga exposure area for the Mw 9.0 Hikurangi scenario, with heritage land area polygons overlaid

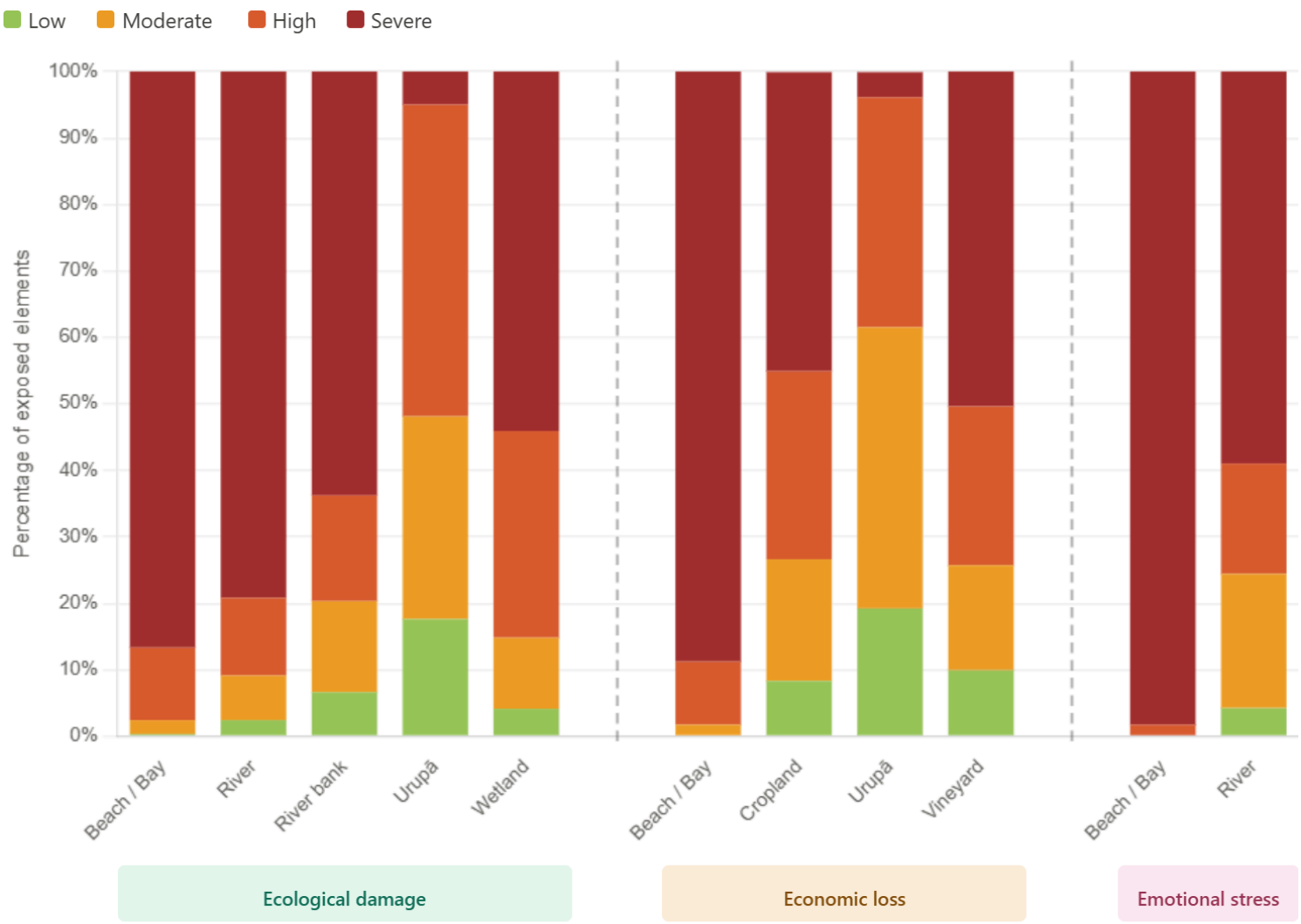
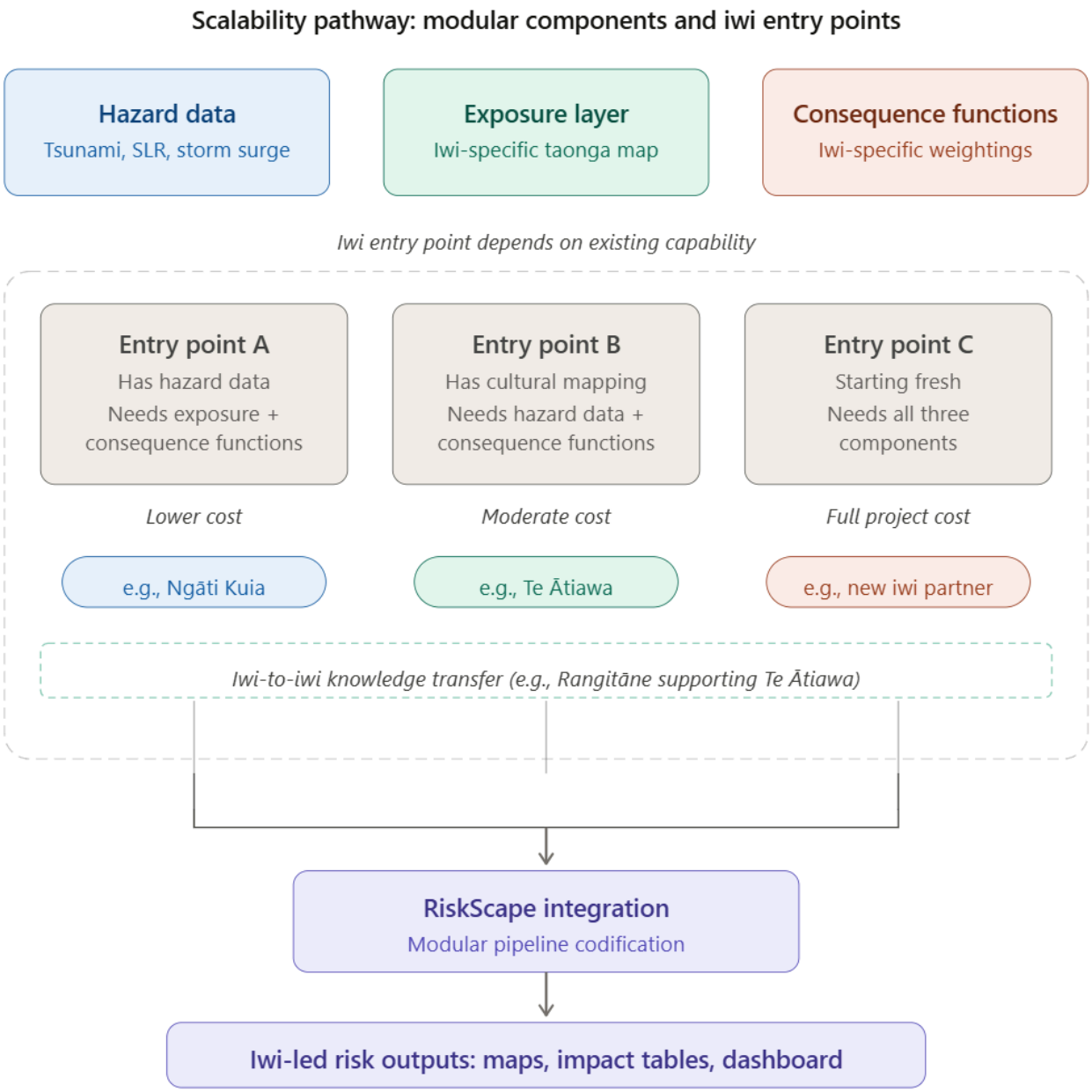


Figure 6. RiskScape output — percentage of exposed taonga elements by impact level and consequence domain, Mw 9.0 Hikurangi tsunami scenario at present-day sea level.

Figure 8

Stacked bar chart showing percentage of exposed taonga elements by impact level (Low, Moderate, High, Severe) across Ecological Damage, Economic Loss, and Emotional Stress domains for the Mw 9.0 Hikurangi tsunami scenario. Cultural Disruption — the fourth consequence domain — is not presented as a standalone output category because Rangitāne o Wairau conceptualise it as a cross-cutting dimension of loss inherently embedded within the other three domains. Ecological Damage, Economic Loss, and Emotional Stress each represent a distinct expression of cultural disruption and together constitute its full analytical representation within the model



gure 9. Scalability pathway showing modular components, iwi entry points by readiness, and convergence on RiskScape integration.

Figure 9

Scalability pathway diagram showing the modular relationship between hazard data, cultural exposure layers, and consequence functions, and the entry points for iwi at different stages of readiness