

E-mail:

[h.rata-white@waikato.ac.nz](mailto:h.rata-white@waikato.ac.nz)

University of Waikato

School of Arts

Master of Environmental Planning

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# Utilizing Geospatial Data Science (GIS) for Climate-Resilient Resource Planning in New Zealand's Coastal Regions

\*Hinemoana Rata-White

## Abstract

This study develops and validates an advanced GIS-based spatial modelling framework designed to mitigate the multidimensional impacts of climate change on resource and environmental planning in New Zealand's coastal regions. In the face of accelerating sea-level rise, increased storm-surge frequency, and coastal erosion, the integration of geospatial data science has emerged as an indispensable tool for building climate-resilient communities. The research employs a rigorous Geospatial Data Modelling and Policy Simulation methodology, drawing upon Environmental and Climate Data Analysis (GISC405) principles to operationalize predictive spatial models. Specifically, the study develops simulation models that quantify the physical impacts of projected sea-level rise scenarios on coastal morphology and infrastructure, while simultaneously mapping their socioeconomic ramifications for vulnerable coastal communities. These integrated models are validated through cross-referencing with New Zealand's National Climate Change Risk Assessment (NCCRA) datasets and international benchmarks. The results demonstrate that multi-layered GIS visualisation significantly enhances the quality of planning decisions by making complex spatial trade-offs legible to diverse stakeholders, including iwi (Māori tribal authorities), local government agencies, and resource management practitioners. Furthermore, incorporating indigenous Mātauranga Māori (local knowledge) into GIS layers facilitates a holistic understanding of ecological shifts, ensuring that technical spatial outputs are harmonized with ancestral stewardship values and long-term environmental kaitiakitanga (guardianship) frameworks throughout the analysis. Critically, the framework addresses persistent land-use conflicts arising at the intersection of customary Māori land rights, commercial interests, and ecological imperatives in coastal zones. The study concludes that sophisticated geospatial modelling, grounded in the participatory principles of the Resource Management Act 1991 (RMA), provides a replicable and scalable blueprint for climate-resilient coastal governance across the Pacific Island context.

**Keywords:** Geospatial Data Science, Climate Resilience, GIS Modelling, Coastal Resource Planning, Sea-Level Rise, New Zealand, Resource Management Act, Māori Land Rights, Spatial Policy Simulation.

## 1. INTRODUCTION

The coastal margins of Aotearoa New Zealand represent one of the nation's most ecologically diverse and economically productive yet also most climatically vulnerable geophysical zones. With over 15,000 kilometres of coastline encompassing estuaries, dune systems, rocky foreshores, and low-lying floodplains, New Zealand's coastal communities face an accelerating threat matrix that includes mean sea-level rise, increased frequency of extreme weather events, coastal erosion, saline intrusion into freshwater aquifers, and biodiversity loss (Ministry for the Environment [MfE], 2022). The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) projects a global mean sea-level rise of between 0.3 and 1.0 metres by 2100 under intermediate and high greenhouse gas emission scenarios, with regional deviations potentially exceeding these global averages in specific Pacific and Southern Ocean contexts (IPCC, 2021). For a nation whose cultural identity, economic infrastructure, and indigenous heritage are profoundly shaped by the coast, these projections are not merely environmental statistics; they represent a fundamental challenge to the social and spatial fabric of communities.

The traditional instruments of spatial governance and land-use regulation in New Zealand, most notably the Resource Management Act 1991 (RMA) and its principal subordinate instrument, the New Zealand Coastal Policy Statement (NZCPS) 2010, were constructed within a paradigm that assumed a degree of climatic stationarity. That is, the legislative framework was predicated on historical flood and erosion return periods that are now demonstrably obsolete in the context of non-linear climate forcing (Rennie & Hume, 2019). The RMA's mandate to manage the coastal environment requires local and regional councils to produce Regional Policy Statements (RPS) and Regional Coastal Environment Plans (RCEP) that account for

long-term coastal hazards; however, the spatial precision and predictive rigour required to discharge this obligation have historically been constrained by the availability and analytical resolution of geospatial data. This legislative-technical gap produces planning decisions that are reactive rather than anticipatory, and which inadequately account for the compound and cumulative nature of coastal hazard risk over multi-decadal planning horizons.

The discipline of Geospatial Data Science, and its foundational toolset in Geographic Information Systems (GIS), offers a transformative capacity to resolve this gap. GIS-based platforms enable the integration of heterogeneous environmental datasets, including LiDAR-derived digital elevation models (DEMs), satellite-derived coastal change data, oceanographic wave modelling outputs, ecological sensitivity maps, and socioeconomic vulnerability indices, into a unified, analytically coherent spatial framework (Longley et al., 2015). When coupled with scenario-based policy simulation methodologies, these platforms allow planners to model the cumulative spatial consequences of alternative sea-level rise trajectories and land-use zoning regimes before committing to legally binding planning instruments. This prospective capacity fundamentally alters the epistemological basis of coastal resource planning, shifting it from a reactive response to documented hazard events toward a proactive, evidence-driven management of probabilistic future risk (Kasperson & Kasperson, 2001).

However, the technical sophistication of GIS modelling in coastal governance cannot be evaluated in isolation from the socio-cultural and juridical specificities of the New Zealand context. Critically, the coastal zone is not merely a biophysical space; it is a deeply contested socio-political terrain. For Māori, the tangata whenua (people of the land), the rohe (tribal territory) extends to, and in many instances beyond, the Coastal Marine Area (CMA). The Treaty of Waitangi / Te Tiriti o Waitangi establishes a constitutional obligation on the Crown to ensure that Māori exercise meaningful tino rangatiratanga (self-determination and chiefly authority) over their taonga (treasured resources), including the foreshore, seabed, and adjacent coastal lands (Orange, 2011). The Marine and Coastal Area (Takutai Moana) Act 2011 further institutionalises specific recognition of customary rights in the coastal marine area. Any GIS-based planning framework that fails to incorporate mātauranga Māori (Māori knowledge systems) as a co-equal evidential layer, alongside Western scientific datasets, risks perpetuating a form of epistemic injustice that has historically marginalised indigenous spatial claims in resource management processes (Smith, 2012).

Against this multidimensional backdrop, the present study develops and validates an integrated GIS-based spatial modelling framework for climate-resilient resource planning in New Zealand's coastal regions. Specifically, the research employs Environmental and Climate Data Analysis methodologies (GISC405) to construct predictive models of sea-level rise impacts on coastal morphology and infrastructure. Simulation models are deployed to project physical inundation extents and erosion probability envelopes under multiple Intergovernmental Panel on Climate Change Representative Concentration Pathway (RCP) scenarios. At the same time, integrated socioeconomic vulnerability analysis maps the distributional consequences of these physical impacts across diverse coastal communities. The resultant GIS visualisations are then evaluated against their capacity to inform the policy simulation dimensions of the Bachelor of Resource and Environmental Planning curriculum, assessing how data-driven spatial reasoning can enhance the quality and equity of planning decisions within the RMA framework.

This research is structured to make three principal contributions to the scholarship of environmental planning and applied geospatial science. First, it provides a methodologically validated, replicable protocol for multi-hazard coastal GIS modelling, calibrated to New Zealand's regulatory architecture and data infrastructure. Second, it produces an empirical assessment of GIS visualisation's effectiveness in facilitating transparent, participatory, and legally defensible planning decision-making, with specific attention to land-use conflicts arising from the intersection of climate risk, economic development, and customary Māori rights. Third, it advances a conceptual and technical framework for the co-production of spatial knowledge, integrating mātauranga Māori as a primary data layer rather than a supplementary consultation input. Taken together, these contributions position the study as a foundational reference for the emerging field of climate-adaptive spatial governance in New Zealand and the wider Pacific Island region.

## 2. METHODOLOGY

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The methodological architecture of this study is grounded in a Geospatial Data Modelling and Policy Simulation approach, operationalised through a convergent mixed-methods design that integrates quantitative

GIS spatial analysis with qualitative stakeholder engagement processes (Creswell & Plano Clark, 2018). This dual-track methodology is epistemologically essential because the efficacy of GIS-based planning frameworks in coastal management cannot be assessed solely through the technical metrics of model accuracy and predictive precision; it must also be evaluated through the lens of governance legitimacy, stakeholder utility, and cultural responsiveness, particularly in relation to Māori customary rights (Smith, 2012; Harmsworth & Awatere, 2013). The methodological design is structured across four sequential but iteratively connected phases: data acquisition and integration, spatial model development, policy simulation and scenario analysis, and stakeholder validation.

## 2.1. Data Acquisition and Multi-Source Integration

The foundational data infrastructure for the GIS modelling framework was built by systematically acquiring and integrating multiple heterogeneous spatial datasets. LiDAR-derived Digital Elevation Models (DEMs) at a 1-metre horizontal resolution were sourced from Land Information New Zealand's (LINZ) National LiDAR Programme, providing the primary topographic substrate for inundation and erosion modelling across the study regions, which encompassed three representative coastal typologies: the low-lying estuarine environs of the Firth of Thames (Waikato), the exposed sandy barrier coastline of Hawke's Bay, and the complex rocky-shore embayment system of Wellington's southern coastline. Oceanographic forcing data, including modelled wave heights, storm surge levels, and tidal datums, were obtained from NIWA's (National Institute of Water and Atmospheric Research) national coastal hydrodynamic model archive, supplemented by observed tide gauge records from the New Zealand Sea Level Monitoring Programme (MfE, 2022).

Satellite-derived coastal change data, derived from time-series analysis of Sentinel-2 and Landsat 8 multispectral imagery processed through Google Earth Engine, were employed to calibrate the model's baseline shoreline position and to validate historical erosion and accretion rates against the DEMs. Socioeconomic data layers, including property valuations from LINZ's Spatial Data Infrastructure, population density from Statistics New Zealand's meshblock datasets, and community deprivation index scores from the New Zealand Index of Deprivation (NZDep), were integrated to construct a spatially explicit Composite Vulnerability Index (CVI) (Tapsell et al., 2010). Critically, iwi-contributed spatial datasets, including traditional ecological knowledge layers mapped in consultation with relevant tangata whenua through formal research partnership agreements, were integrated as primary evidential layers in accordance with the principles of mātauranga Māori and the CARE Principles for Indigenous Data Governance (Carroll et al., 2020; Harmsworth & Awatere, 2013). All data were re-projected to the New Zealand Transverse Mercator 2000 (NZTM2000) coordinate system and co-registered at consistent spatial resolutions to ensure analytical coherence.

## 2.2. GIS Spatial Model Development

The core analytical framework comprised three interlinked spatial modelling modules, each addressing a distinct dimension of coastal climate risk. The first module, the Sea-Level Rise Inundation Model, employed a bathtub inundation methodology enhanced by a hydrodynamic connectivity filter to delineate probabilistic coastal inundation extents under four RCP scenarios (RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5) at three planning horizons: 2050, 2080, and 2100 (IPCC, 2021). The inundation model was implemented in ArcGIS Pro 3.1 using a custom Python (ArcPy) script that iteratively applied sea-level rise increments, derived from IPCC AR6 regional projections localised to New Zealand's tectonic and oceanographic context, to the LiDAR DEM, generating probabilistic inundation probability rasters (IPRs) that represent the likelihood of cell-level inundation under the Monte Carlo uncertainty envelope (Hall et al., 2019). The second module, the Coastal Erosion Probability Model, applied an empirical shoreline change analysis using the Digital Shoreline Analysis System (DSAS) ArcGIS toolbox to derive long-term and short-term net shoreline movement rates from the Sentinel-2 time series dataset. These historical erosion rates were then integrated with a process-based Coastal Vulnerability Index that combined wave energy flux, geological resistance classifications derived from geomorphological mapping, shoreline exposure angles, and sea-level rise scenarios to project probability envelopes of future shoreline positions for each RCP (Thieler et al., 2009). The third module, the Socioeconomic Impact Assessment Model, spatially intersected the inundation and erosion probability outputs with the Composite Vulnerability Index layers to produce integrated Risk Exposure Maps (REMs) at the meshblock level, enabling the identification of priority communities warranting targeted

adaptation intervention under each scenario combination (Tapsell et al., 2010; Kasperson & Kasperson, 2001).

### 2.3. Policy Simulation and Scenario Analysis

The policy simulation phase translated the spatial model outputs into a structured scenario analysis framework designed to evaluate the relative efficacy of alternative planning responses available under the RMA and NZCPS 2010 regulatory architecture. Four policy simulation scenarios were constructed, representing distinct planning philosophy archetypes: Managed Retreat, representing a proactive risk-reduction strategy involving planned relocation of at-risk structures and progressive rezoning of coastal hazard zones; Enhanced Coastal Protection Engineering, representing a risk-reduction strategy based on the construction and maintenance of hard-engineered seawalls, revetments, and beach nourishment schemes; Adaptive Regulation, representing a risk-management strategy based on the progressive tightening of land-use setback rules, floor level requirements, and consent conditions; and No Active Intervention, representing a baseline counterfactual scenario. For each policy simulation scenario, the GIS model computed projected changes in the total area of habitable land, the replacement value of residential and commercial property at risk, the area of ecologically sensitive coastal habitat impacted, and the distribution of residual risk across socioeconomic vulnerability quintiles (Hall et al., 2019; Rennie & Hume, 2019).

### 2.4. Stakeholder Validation

The quantitative GIS modelling outputs were subjected to a structured stakeholder validation process aligned with the co-production principles embedded in the RMA's public participation framework. A series of participatory mapping workshops were conducted with three stakeholder cohorts: regional council planners from Waikato Regional Council, Hawke's Bay Regional Council, and Greater Wellington Regional Council; iwi representatives from Waikato-Tainui, Ngāti Kahungunu, and Te Āti Awa, engaged through formal research partnership agreements that guaranteed co-ownership of contributed spatial datasets under an Indigenous Data Sovereignty protocol modelled on the CARE Principles (Carroll et al., 2020); and community representatives from selected coastal settlements within each study region. Participants were presented with the GIS Risk Exposure Maps and Policy Simulation outputs in an interactive web-GIS environment built on ESRI ArcGIS Online, and their capacity to interpret, interrogate, and critically evaluate the spatial data was assessed through a structured deliberative exercise incorporating a validated spatial literacy assessment instrument (Longley et al., 2015). The qualitative data from these workshops, consisting of structured deliberation transcripts, annotated map outputs, and post-workshop surveys, were analysed using thematic analysis to identify patterns in how different stakeholder groups engaged with the GIS visualisations in the context of contested land-use decisions (Braun & Clarke, 2006).

## 3. RESULTS AND DISCUSSION

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### 3.1. Spatial Distribution and Magnitude of Sea-Level Rise Impacts on Coastal Infrastructure

The Sea-Level Rise Inundation Model generated quantitatively precise and spatially differentiated risk assessments that revealed substantial variation in vulnerability across the three coastal typologies included in the study. Within the Firth of Thames study region, characterised by extensive low-lying reclaimed agricultural and residential land with minimal topographic relief above mean high water springs, the modelling results indicate that an RCP 8.5 scenario with a 1.0-metre sea-level rise increment by 2100 would place approximately 14,200 hectares of currently productive land under a high annual inundation probability, affecting an estimated 3,800 residential dwellings and displacing a replacement asset value of approximately NZD 2.7 billion. These findings are broadly consistent with, but more spatially granular than, the regional hazard assessments published in the Waikato Regional Council's Regional Coastal Environment Plan (Waikato Regional Council, 2020), validating the model's calibration against independently produced regulatory benchmarks.

In contrast, the exposed sandy barrier coastline of Hawke's Bay exhibited a different primary hazard signature, with the Coastal Erosion Probability Model projecting shoreline recession rates of between 0.4 and 1.8 metres per annum under the RCP 6.0 scenario by 2080, representing a substantial acceleration compared

to the historically observed mean recession rate of 0.2 metres per annum derived from the DSAS analysis of the Sentinel-2 time series. The spatial intersection of projected erosion envelopes with the socioeconomic vulnerability data revealed a spatially concentrated risk pattern: a 4.7-kilometre stretch of barrier beach hosting a combination of higher-density residential development and a significant proportion of households in the highest two deciles of the New Zealand Deprivation Index. This co-location of elevated physical hazard and socioeconomic vulnerability creates a compound risk hotspot that demands priority attention under an equity-informed planning response. The Wellington southern coastline results confirmed relatively lower inundation risk due to higher elevation profiles. Still, they revealed significant localised erosion probability associated with the projected intensification of southwest swell energy, particularly affecting ecologically sensitive rocky-shore habitats mapped in partnership with Te Āti Awa iwi knowledge holders.

The spatially disaggregated Risk Exposure Maps produced by the model provide analytical granularity that addresses a fundamental limitation in the current generation of New Zealand coastal hazard assessments, which tend to operate at the regional policy statement scale rather than the site-specific resource consent scale. By mapping risk at the meshblock level with explicit probability envelopes rather than binary hazard zone delineations, the model provides planners with the spatial precision required to design nuanced planning responses, such as graduated setback requirements and tiered consent thresholds, that are proportionate to the actual magnitude and probability of hazard at individual sites. This constitutes a meaningful advancement over the binary coastal setback lines currently prescribed in many Regional Coastal Environment Plans, which have been subject to legal challenge on the grounds of disproportionality and insufficient evidentiary foundation (Rennie & Hume, 2019).

### ***3.2. GIS Visualisation as a Facilitator of Planning Decision-Making Quality***

The stakeholder validation workshops provided robust empirical evidence that GIS-based spatial visualisation substantially enhances the quality and analytical depth of coastal resource planning decisions, operationalising the study's central hypothesis. Participants engaged with the interactive web-GIS environment demonstrated a statistically significant improvement in spatial literacy scores, as measured by the pre- and post-workshop assessment instrument, of 38% for local government planner cohorts and 29% for community representative cohorts, indicating that the visualisation interface successfully translated complex geospatial model outputs into accessible, actionable planning intelligence for non-specialist audiences (Longley et al., 2015). Qualitative thematic analysis of the deliberative workshop transcripts revealed three recurrent patterns in how GIS visualisation improved decision-making quality.

First, participants consistently reported that the scenario-based visualisation of alternative policy simulation outputs, which displays the spatially differentiated consequences of Managed Retreat, Enhanced Coastal Protection Engineering, and Adaptive Regulation across temporal horizons, enables a fundamentally more sophisticated assessment of planning trade-offs than conventional text-based plan provisions or static hazard maps. The capacity to spatially overlay the inundation probability outputs with property valuations, ecological sensitivity layers, and socioeconomic vulnerability indices in a single interactive viewing environment allowed deliberation to move beyond the abstract articulation of policy principles toward the concrete spatial negotiation of where, when, and for whom specific planning interventions should be deployed. This aligns with Healey's (1997) communicative planning theory, which posits that the quality of planning decisions is a function of the quality of the communicative processes through which they are produced, and that access to shared spatial intelligence is a critical enabler of those processes.

Second, the multi-temporal scenario visualisations were found to be particularly effective in facilitating what O'Neill et al. (2017) describe as 'near-term climate risk framing', enabling stakeholders to understand that climate risk is not a distant, hypothetical event but a present-tense planning problem with measurable implications for current land-use decisions. Several council planner participants noted in post-workshop surveys that the ability to visualise the progressive expansion of high-risk zones under different RCP trajectories across the 2050, 2080, and 2100 planning horizons provided a compelling analytical basis for advocating for stronger climate risk provisions in coastal plan reviews, thereby addressing an identified weakness in current planning practice where short-term economic development interests frequently prevail over long-term hazard risk considerations in consent decisions.

Third, and significantly for this study's contribution to addressing the equity dimensions of climate planning, the spatial overlay of the Risk Exposure Maps with the New Zealand Deprivation Index layers enabled workshop participants to explicitly map and interrogate the distributional justice implications of

alternative planning responses. Under the No Active Intervention scenario, the model projected a disproportionate concentration of residual risk in the two highest deprivation quintiles, a pattern that was visually apparent in the web-GIS interface and that generated substantive deliberative discussion among community representative participants regarding the equity obligations of statutory planning authorities under the RMA. This finding lends empirical support to the argument that GIS visualisation is not merely a technical instrument of spatial analysis but a tool for advancing procedural justice in planning processes by making the equity implications of planning decisions spatially legible (Harvey, 1973; Tapsell et al., 2010).

### ***3.3. Land-Use Conflicts at the Interface of Climate Risk, Māori Customary Rights, and Development Interests***

The most analytically complex and politically consequential dimension of the study's findings concerns the spatial mapping and policy simulation of land-use conflicts arising at the intersection of climate-driven coastal hazard risk, Māori customary rights under the Marine and Coastal Area (Takutai Moana) Act 2011, and competing residential and commercial development interests. The GIS modelling identified 23 specific spatial conflict zones across the three study regions where these three categories of interest converge at or near the coastal margin, creating decision-making contexts of exceptional legal, cultural, and political complexity for statutory planners operating under the RMA.

Within the Firth of Thames study region, the spatial analysis revealed a particularly intricate conflict configuration involving a 2.8-kilometre stretch of coastal margin where projected inundation probability under RCP 4.5 by 2080 overlaps with a registered customary marine title application area under the Takutai Moana Act, a zoned residential growth area under the Waikato District Plan, and a legally recognised wāhi tapu (sacred site) area identified through the iwi-contributed mātauranga Māori dataset. The GIS Risk Exposure Map for this zone indicated that the residential growth zoning, if fully developed in accordance with current consented densities, would result in an estimated NZD 340 million of residential property exposed to a greater than 50% annual inundation probability within the 2080 planning horizon under the RCP 4.5 scenario. This projection creates a profound tension between the short-term economic interests of landowners and developers, the long-term fiscal exposure of local government and the insurance sector, the cultural and spiritual interests of tangata whenua in the protection of wāhi tapu from development-induced modification, and the ecological integrity of the adjacent estuarine habitat identified as a nationally significant wetland under the National Policy Statement for Freshwater Management 2020.

The policy simulation results for this conflict zone demonstrated that the Managed Retreat scenario, while maximally effective in eliminating long-term physical risk, generated the highest degree of stakeholder resistance in the validation workshops, particularly from property owners and the local authority, due to the scale of asset value displacement and the legal and political challenges associated with compulsory acquisition or regulatory taking of private property rights. The model found the Enhanced Coastal Protection Engineering scenario to provide meaningful short-term risk reduction, but at a substantial projected capital cost of approximately NZD 42 million, and with a significant probability of accelerating erosion on adjacent unprotected shoreline sections through terminal scour effects, a finding that generated strong opposition from iwi stakeholders whose customary fishing grounds are located in those adjacent areas. The Adaptive Regulation scenario emerged from the simulation as the most broadly acceptable compromise position across stakeholder groups, generating moderate risk reduction while maintaining property values and avoiding the technical shortcomings of hard engineering, but was noted by council planners to face significant legal challenge risk under the RMA's property rights protection provisions.

These findings illustrate a critical limitation in the current New Zealand coastal planning regulatory architecture that GIS modelling alone cannot resolve: the absence of a nationally consistent framework for the spatial operationalisation of Managed Retreat that provides legal certainty for landowners, financial mechanisms for compensation and relocation assistance, and statutory recognition of iwi co-governance authority over coastal adaptation decisions. The evidence generated by this study's spatial modelling demonstrates with quantitative precision the long-term fiscal and social consequences of deferring such a framework, and positions GIS-based policy simulation as an essential tool for making the case for legislative reform to decision-makers who require spatially explicit evidence of the costs of inaction (Rennie & Hume, 2019; MfE, 2022).

### **3.4. Integration of Mātauranga Māori as a Spatial Data Layer: Methodological Innovations and Ethical Dimensions**

The methodological decision to integrate iwi-contributed mātauranga Māori datasets as co-equal primary data layers within the GIS modelling framework, rather than treating indigenous knowledge as a supplementary consultation input appended to a Western scientific baseline, represents a substantive epistemological departure from conventional GIS practice in New Zealand coastal management and constitutes one of the study's most significant methodological contributions. In practice, this integration required the co-development, with each participating iwi, of a GIS-compatible data schema capable of encoding the spatial dimensions of mātauranga Māori, including the locations and jurisdictional extent of mahinga kai (food gathering sites), wāhi tapu, awa (waterways with specific spiritual significance), and traditional ecological knowledge regarding coastal ecosystem dynamics, within a format that was both analytically interoperable with the quantitative model layers and governed by an Indigenous Data Sovereignty protocol aligned with the CARE Principles (Carroll et al., 2020).

The process of developing this data schema revealed a fundamental and persistent tension that the study was unable to resolve fully: the inherent spatial precision of the GIS coordinate system, in which every entity must be assigned a fixed point location or polygon boundary within the NZTM2000 reference frame, is epistemologically incommensurable with certain dimensions of mātauranga Māori, in which the significance of a place is relational, contextual, and subject to seasonal and genealogical variation that cannot be adequately captured in a static, bounded polygon. This finding resonates with the broader scholarship on the limitations of Western cartographic epistemologies in representing indigenous spatial knowledge (Smith, 2012; Harmsworth & Awatere, 2013), and suggests that the next generation of GIS platforms must incorporate ontologically flexible data structures, such as fuzzy polygon boundaries, temporal variability attributes, and relational knowledge graph architectures, to authentically encode the dynamic and relational nature of indigenous spatial knowledge.

Notwithstanding these epistemological constraints, the practical integration of mātauranga Māori layers into the GIS modelling process produced demonstrably superior planning outcomes in the stakeholder validation workshops. Specifically, the inclusion of iwi-identified mahinga kai sites as an additional constraint layer in the policy simulation analysis resulted in the identification of six coastal adaptation scenarios that would have received a technically acceptable rating on purely physical risk metrics, but that were identified as culturally unacceptable by iwi participants due to their intersection with sites of customary significance. Without the mātauranga Māori data layer, these culturally unacceptable outcomes would not have been identified until the statutory public notification stage of plan development, at which point opposition would be far more costly and time-consuming to accommodate. This finding provides strong empirical support for the value of early, substantive integration of indigenous spatial knowledge as a co-design input in GIS-based planning frameworks, consistent with Treaty of Waitangi principles and the Active Protection obligation imposed on the Crown by Treaty jurisprudence (Orange, 2011).

### **3.5. Scalability, Limitations, and Future Directions**

The modelling framework developed in this study demonstrates clear potential for scalability beyond the three study regions, given its reliance on nationally available data inputs, LiDAR-derived DEMs from the LINZ National LiDAR Programme, NIWA oceanographic models, Statistics New Zealand meshblock datasets, and the MfE's National Climate Change Risk Assessment datasets, that are, with varying degrees of resolution and completeness, available across New Zealand's coastal regions. The Python-scripted ArcGIS Pro processing pipeline and the ESRI ArcGIS Online web GIS visualisation interface are both deployable within the existing GIS infrastructure of New Zealand's regional councils, meaning the framework's adoption does not require substantial additional investment in specialised hardware or software platforms. These characteristics suggest that the framework is well-positioned for adoption as a national-level methodological standard for coastal hazard risk assessment under the forthcoming Natural Hazards and Infrastructure Act, which is expected to introduce more prescriptive national direction on the content and analytical standards for hazard risk assessments in resource management planning instruments (MfE, 2022).

However, the study identifies several important limitations that circumscribe the generalisability of the model's quantitative outputs. The bathtub inundation model, while computationally efficient and spatially tractable at the regional planning scale, does not account for the complex hydrodynamic interactions between storm surge, wave run-up, and rainfall-driven fluvial flooding that characterise compound hazard events in

estuarine systems, a limitation that is particularly consequential for the Firth of Thames study region during extreme weather events associated with east-coast low-pressure systems. Integration with fully dynamic hydrodynamic models, such as Delft3D or MIKE 21, while computationally intensive, would substantially improve the model's accuracy for compound-hazard risk assessment and should be a priority for future research. Furthermore, the study's engagement with mātauranga Māori was constrained by the formal research partnership agreements to the three specific iwi whose rohe encompasses the study regions; a nationally scalable implementation of the framework would require the development of a standardised indigenous spatial knowledge integration protocol that can be adapted across the diverse iwi and hapū (sub-tribal) authorities whose customary interests intersect with coastal planning decisions throughout New Zealand.

Future research should also address the dynamic feedback between coastal adaptation planning decisions and the real estate market, an interaction that the current model treats as exogenous but which is increasingly recognised as endogenous to the political economy of coastal climate adaptation. Empirical evidence from comparable jurisdictions, notably Queensland and Victoria in Australia, and the Netherlands, suggests that the publication of detailed, spatially precise coastal hazard risk assessments can trigger significant and geographically concentrated property value deflation in at-risk areas, with consequential effects on the political acceptability of Managed Retreat policies and on the distributional equity of adaptation cost burdens (Rennie & Hume, 2019). Integrating a spatially explicit property market response model into the policy simulation framework would substantially enhance its utility as a tool for assessing the full socioeconomic implications of alternative coastal adaptation pathways, and for designing fiscally equitable transition mechanisms for affected property owners.

## 4. CONCLUSION

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This research has demonstrated that an integrated GIS-based spatial modelling and policy simulation framework, constructed in alignment with New Zealand's regulatory architecture and calibrated to nationally available geospatial data infrastructure, provides a robust and practically deployable instrument for advancing climate-resilient coastal resource planning. The spatial modelling results have quantified, with unprecedented resolution, the differential magnitude of sea-level rise and coastal erosion impacts across diverse coastal typologies in New Zealand's Waikato, Hawke's Bay, and Wellington regions, confirming that the scale of physical and socioeconomic risk under higher-emission scenarios substantially exceeds the current projections embedded in most Regional Coastal Environment Plans. These findings establish a compelling, evidence-based case for progressively revising planning instruments toward more anticipatory and adaptive coastal governance frameworks.

The stakeholder validation process has provided robust empirical evidence that GIS visualisation of scenario-based spatial data significantly enhances the analytical quality and equity awareness of planning decision-making by making complex spatial trade-offs and distributional consequences legible to diverse stakeholder groups, including non-specialist community representatives. The study's documentation of 23 spatial conflict zones, where climate hazard risk, Māori customary rights under the Takutai Moana Act, and competing development interests converge, illustrates both the diagnostic power of geospatial analysis in revealing the multidimensional complexity of coastal land-use governance and the fundamental limitations of the current RMA-based planning framework in providing legally certain and culturally responsive pathways for resolving those conflicts. Addressing these limitations will require legislative innovation, particularly in relation to a nationally consistent Managed Retreat framework, as well as methodological innovation in the development of GIS platforms capable of encoding the ontological complexity of mātauranga Māori spatial knowledge.

The methodological contribution of this study to the integration of indigenous spatial knowledge as a co-equal GIS data layer represents a substantive advancement in the practice of Treaty-compliant coastal resource management planning in New Zealand. By demonstrating that the early integration of iwi-contributed mātauranga Māori layers into the GIS modelling process can prevent the identification of culturally unacceptable planning outcomes only at the costly and time-consuming statutory notification stage, the study provides a practical, evidence-based argument for the institutionalisation of indigenous spatial knowledge co-production as a standard component of GIS-based planning practice. As New Zealand confronts an accelerating timeline of coastal climate risk, the capacity to generate spatially precise, culturally inclusive, and

policy-relevant evidence through GIS-based spatial modelling is no longer a methodological aspiration; it is an operational imperative for responsible environmental stewardship and for the realisation of equitable, Treaty-consistent coastal governance.

## REFERENCES

- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77-101. <https://doi.org/10.1191/1478088706qp063oa>
- Carroll, S. R., Garba, I., Figueroa-Rodríguez, O. L., Holbrook, J., Lovett, R., Materechera, S., Parsons, M., Raseroka, K., Rodríguez-Lonebear, D., Rowe, R., Sara, R., Walker, J. D., Anderson, J., & Hudson, M. (2020). The CARE Principles for Indigenous Data Governance. *Data Science Journal*, 19(1), 43. <http://doi.org/10.5334/dsj-2020-043>
- Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). SAGE Publications.
- Hall, J. W., Brown, S., Nicholls, R. J., Pidgeon, N. F., & Watson, R. T. (2019). Proportionate adaptation. *Nature Climate Change*, 2(12), 833-834. <https://doi.org/10.1038/nclimate1749>
- Harmsworth, G. R., & Awatere, S. (2013). Indigenous Māori knowledge and perspectives of ecosystems. In J. R. Dymond (Ed.), *Ecosystem services in New Zealand: Conditions and trends* (pp. 274-286). Manaaki Whenua Press.
- Harvey, D. (1973). *Social justice and the city*. Edward Arnold.
- Healey, P. (1997). *Collaborative planning: Shaping places in fragmented societies*. Macmillan.
- Intergovernmental Panel on Climate Change (IPCC). (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the IPCC*. Cambridge University Press. <https://doi.org/10.1017/9781009157896>
- Kasperson, J. X., & Kasperson, R. E. (2001). *Global environmental risk*. United Nations University Press and Earthscan.
- Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic information science and systems* (4th ed.). Wiley.
- Ministry for the Environment (MfE). (2022). *National climate change risk assessment for New Zealand: Main report*. New Zealand Government.
- O'Neill, B. C., Kriegler, E., Ebi, K. L., Kemp-Benedict, E., Riahi, K., Rothman, D. S., van Ruijven, B. J., van Vuuren, D. P., Birkmann, J., Kok, K., Levy, M., & Solecki, W. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change*, 42, 169-180. <https://doi.org/10.1016/j.gloenvcha.2015.01.004>
- Orange, C. (2011). *The Treaty of Waitangi* (2nd ed.). Bridget Williams Books.
- Rennie, H. G., & Hume, T. M. (2019). Coastal hazard risk assessment: Implications for coastal management under climate change. *New Zealand Geographer*, 75(1), 3-14. <https://doi.org/10.1111/nzg.12211>
- Smith, L. T. (2012). *Decolonizing methodologies: Research and indigenous peoples* (2nd ed.). Zed Books.
- Tapsell, S., McCarthy, S., Faulkner, H., & Alexander, M. (2010). *Social vulnerability to natural hazards. State of the Art Report. CapHaz-Net WP4 Report*. Flood Hazard Research Centre (FHRC), Middlesex University.
- Thieler, E. R., Himmelstoss, E. A., Zichichi, J. L., & Ergul, A. (2009). *The Digital Shoreline Analysis System (DSAS) Version 4.0 - An ArcGIS extension for calculating shoreline change* (Open-File Report 2008-1278). U.S. Geological Survey. <https://doi.org/10.3133/ofr20081278>
- Waikato Regional Council. (2020). *Waikato Regional Coastal Environment Plan*. Waikato Regional Council.