THE LARGE-SCALE APPLICATION OF A NEW RAPID TSUNAMI INUNDATION MODEL TO NEW ZEALAND'S COAST

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New Zealand is highly susceptible to tsunami inundation given its proximity to Pacific plate boundaries and local faults. Pre-emptive inundation modelling studies allow communities and authorities to prepare for possible inundation. Current tsunami inundation models are either efficient but highly simplified, or accurate but computationally expensive. Furthermore, simplified methods are often applied to regions with limited funding or resources, hence often tsunami evacuation zones are informed by these very simple methods (including bathtub and attenuation method) within New Zealand (Paulik et al,, 2020). Thus, a practical void is apparent, and an efficient inundation model that doesn't compromise on accuracy is desired. Therefore, the new rapid tsunami inundation model aims to fill this void, enabling not only efficient, accurate local assessments, but also comprehensive large-scale assessments.

The development of the new rapid tsunami inundation model is based on the Bernoulli energy conservation equation and simple hydraulic principles (energy conservation with friction loss), working as a two-dimensional hydrodynamic model. It uses shoreline wave-crest level, land elevation, and hydraulic roughness (assigned based on land cover) as the input parameters and systematically progresses inland, calculating the inundation. However, some limitations arise from the simplification, notably the lack-of mass conservation solving, thus affecting the calculation of inundation in regions of severe topographic convergence and divergence. Regardless, the new model has been validated through comparison to the hydrodynamic model COMCOT (Cornell Multi-grid Coupled Tsunami model) where validation simulations at Gisborne and Christchurch, New Zealand, produced similarity indices (F1 scores) upwards of 84.5% for the inundation extent (Figure 1a and Figure 1b). Inundation depth discrepancies were also determined, with over 77% of values being within ± 1 m and over 93% within ± 2 m (with the full range and areas of inundation difference plotted in Figure 1). Shigihara (2022) undertakes a comprehensive analysis on the variation of tsunami inundation by numerical models and determines standard deviations in exceedance of 1 m behind coastal dunes, which is also the location of the largest variations at both Gisborne and Christchurch (as shown in Figure 1c and Figure 1d). Additionally, although the length of coastline at Gisborne was 29km and 13km for Christchurch, the model was highly efficient, and all simulations took less than 100 seconds for a regular desktop computer (CPU: AMD 4700S 8-Core, RAM: 16GB, and SSD: 512 GB) at a 10m resolution.

Based on this validation work and the minimal resources required, the rapid tsunami inundation model: 1) significantly improves on existing simplified approaches where F1 scores were recorded at 61.4% (bathtub) and 44.3% (attenuation) for Gisborne, and 37.4% (bathtub) and 58.9% (attenuation) for Christchurch compared to the F1 scores of the new method at 85.1% at Gisborne and 84.5% at Christchurch, 2) provides a rapid estimate of inundation either from multiple source scenarios, probabilistic shoreline wave heights, or constant wave heights (all which enable the efficient development of inundation envelopes to be used for hazard assessments), and 3) enables inundation assessments in regions with limited resources and funding.

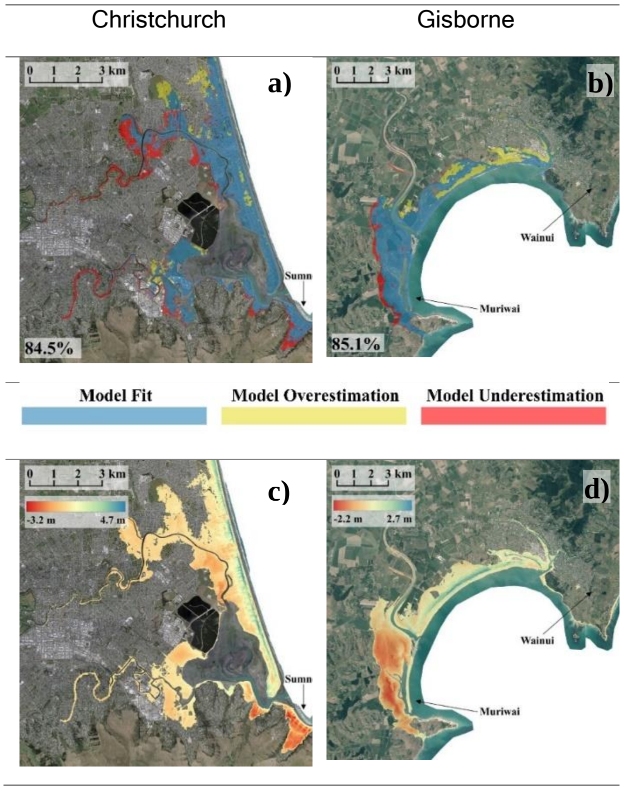

Figure 1 - Inundation results from Christchurch and Gisborne, New Zealand at a 10m resolution. **a)** Comparison of new tsunami inundation model with COMCOT at Christchurch, **b)** Comparison of new tsunami inundation model with COMCOT at Gisborne, **c)** Inundation depth difference between new tsunami inundation model and COMCOT at Christchurch, **d)** Inundation depth difference between new tsunami inundation model and COMCOT at Gisborne

With the development of the new model, large scale assessments of inundation and the resulting national, regional and community impacts are now far more feasible. Additionally, infrastructure hazard assessments can be performed more readily to understand impacts to critical lifelines during tsunami events, including roads, buildings, airports, hospitals and bridges. Whereas current infrastructure exposure studies are limited by the inundation data available. Notably in New Zealand, two methods currently dominate inundation modelling, the attenuation method and numerical modelling based on two-dimensional shallow water equations or Boussinesq equations. The attenuation method accounts for tsunami energy losses during overland propagation by implementing attenuation rules based on empirical data from the 2004 Indian Ocean tsunami that reduce the tsunami maximum potential runup progressively from the shore. Alternatively, numerical modelling solves physics-based equations, however although applied in some cities and exposed locations, isn't extensively applied throughout regions (Paulik et al., 2020).

Therefore, current infrastructure assessments are restricted by the inundation data available and are either therefore based on the agglomeration of multiple independent inundation analyses, where each inundation analysis has its own degree of complexity, physics and input characteristics (Paulik et al,, 2020), or are small-scale and only consider a single city or town (Williams, 2016). Furthermore, often tsunami hazard assessments only consider inundation from two (500-year and 2500-year) return period events or are based on a single specific event. Therefore, a nationwide, consistent infrastructure exposure analysis based on inundation from the new tsunami rapid model provides an excellent insight into infrastructure exposure to tsunami. Additionally, multiple return periods are assessed through the use of comprehensive nationwide tsunami wave height hazard modelling data, which provides the probabilistic tsunami wave height (50th and 84th percentile) at ~ 25km coastal segments for a variety of return period events (100-year, 500-year, 1000-year and 2500-year events) (Power, Burbidge & Gusman, 2021). These wave heights are therefore input for the coastal segments of which the inundation is calculated and a series of comprehensive inundation maps for the range of return periods is developed. Additionally, a large proportion of New Zealand's coastline has been surveyed with LiDAR giving high resolution DEM data; other void areas are compensated by SRTM (Shuttle Radar Topography Mission) data. New Zealand also has an extensive database of land covers, which allocates New Zealand's land into 33 different land cover classes, from which the hydraulic roughness values are applied. Figure 2 outlines the land cover classification groups for New Zealand and the 25 km coastal segments which contain the wave heights for different return periods.

With this large-scale assessment data available, inundation is performed where the output inundation maps correspond to a specific return period event, hence, the exposed infrastructure and land covers within each return periods inundation maps also corresponds to the specific return period event. Additionally, although some regions have a higher tsunami hazard (based on wave height), there may have a smaller exposure and therefore economic loss in such an event, whereas some regions with a smaller hazard may have a larger exposure. Obtaining an overall understanding of exposed infrastructure and land cover in relation to return period helps inform authorities and communities about which areas should be prioritized in decision-making. In the final presentation we aim to show this relationship nationwide, as determining this relationship is a good pre-emptive informative step to build communal resilience to tsunami threat and aids the identification of the communities with the highest exposure and therefore possible funding allocation.

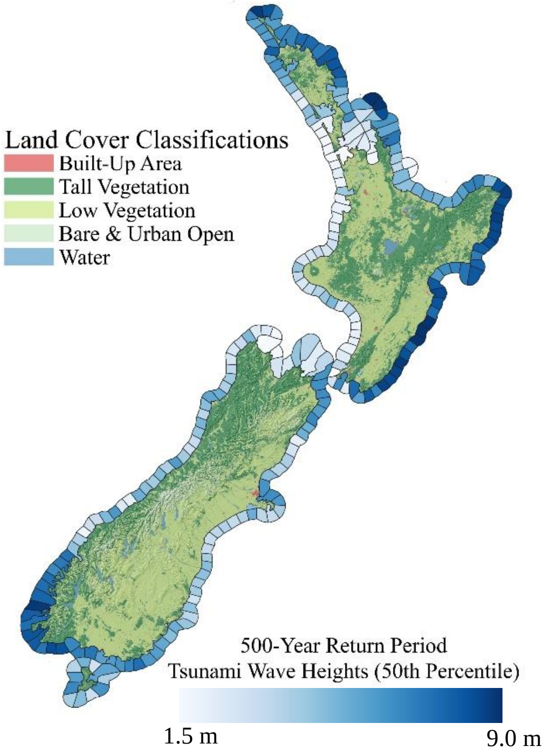

Figure 2 – Nationwide data required to run the model. Grouped land cover classifications from which roughness is assigned based on the group. Shoreline tsunami heights (500-year return period event, 50th Percentile) for 25km segments of coast.

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