Systemic vulnerability of critical infrastructure networks to volcanic multi-hazards

Alana Weir¹, Thomas Wilson¹, Mark Bebbington², Natalia Deligne³, Sarah Beaven¹, Mary Anne Thompson⁴

¹University of Canterbury, NZ; ²Massey University, NZ; ³GNS Science, NZ; ⁴University of Auckland, NZ

The Problem

- Volcanic hazards have different physical behaviours, spatial and temporal extents
- During a volcanic event, multiple hazards can be produced at different stages of the eruption, which can be challenging for decision-makers and infrastructure managers
- Infrastructure systems are highly interdependent, but is under-researched in impact assessment methodologies and resilience planning
- This means that infrastructure systems are not only subject to physical impact from volcanic hazards, but are also subject to systemic, or secondary impact
- There exists no robust, quantitative methodology for assessing the systemic vulnerability of infrastructure networks, particularly with respect to volcanic multi-hazards
- This project aims to address this gap, and apply the methodology in the Taranaki region of New Zealand, where Mt Taranaki has a 33-42% likelihood of erupting within the next 50 years

METHODS

1. Infrastructure networks as schematics
   - Network data from open-source datasets, local councils and utilities, and asset management plans
   - Networks simplified to catchment-scale delivery
   - Uni-directional and bi-directional components are mapped
   - Networks tagged from source to sink

2. Network interdependency mapping
   - Component-component scale interdependencies mapped
   - Data from local councils and utilities, asset management plans and expert judgment
   - Uni- and bi-directional interdependencies accounted for

3. Outage modelling
   - Independent critical infrastructure network represented using the principles of graph theory in the computational software Mathematica
   - The Loss of Service (LoS) metric: Private dwellings without service (DWS) was calculated given the hypothetical failure of each component of the networks (POP, WSS, WTP, WW, OG). DWS was also calculated for the failure of every possible combination of two and three components of the networks.

RESULTS

We measure the potential disruption caused by infrastructure failure by counting the number of private dwellings without service (DWS) in the Taranaki region. This metric is an aggregation of households without service from any lifeline in the network model. For example, if a component results in 10,000 dwellings without power, and 20,000 without water, then a DWS value of 30,000 is assigned.

For one component failure, we find that the DWS value ranges from 9,100-62,800 for one-, two- and three-component failures. The inclusion of the Stratford power network (S1NP) (Fig. 4) results in the presentation of the most disruptive outage scenarios calculated (20,637-109,623 DWS, a 10×4 DWS). One component failure losses in the 1×10×4 DWS band are fairly well distributed between all assessed sectors (water supply (WS), power supply (PS), waste water (WW), and oil and gas (OG)) (Fig. 1).

APPLICATIONS

- Demonstrates the down-stream, trans-network impacts of infrastructure failure
- Can be used as a tool for decision-makers during response activities and response planning
- Can be used as a tool for infrastructure planners and policy-makers, to improve network resilience
- Can be used as an analysis tool for future research, where physical vulnerability functions can be applied to assets, and hazard scenarios can be tested against the infrastructure system response
- Can be used by local councils to assess the most effective and economical network improvements, given the local hazard-scape and infrastructure exposure
- Can be easily adapted to include other critical infrastructure networks, or data on other sectors, such as the agricultural sector
- Can be used as a HAZARD-INDEPENDENT SYSTEMIC VULNERABILITY QUANTIFICATION TOOL.

EX-CYCLONE GITA

During ex-Cyclone Gita (March 2018), fallen trees damaged power distribution lines and water supply pipes. Within 24 hours, 10,000 homes in the Taranaki region were without water; and a further 20,000 homes were under a boil-water notice.

The economic impact on the community was estimated at $4.6 million.

I plan to test my infrastructure model using Ex-Cyclone Gita impact and response data sourced from New Plymouth District Council and PowerNet (the municipal water supplier and regional electricity supplier, respectively).

Future Work

TESTING MITIGATION MEASURES

The interdependent infrastructure model can also test the implementation of physical mitigation measures (i.e. additional assets or lines of defense), and infrastructure management decisions (e.g. technical asset shutdown during an event).

Given a devastating outage scenario, such as the failure of Stratford GXP, what network improvements could prevent loss of service to the region?

This model capability will be utilised later in this work, to provide useful and relevant and useful mitigation recommendations for land and soft engineering during complex volcanic events.

<table>
<thead>
<tr>
<th>CURRENT NETWORK</th>
<th>ADAPTED NETWORK</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Power supply (PS)</td>
<td>- Power supply (PS)</td>
</tr>
<tr>
<td>- Storm water (SW)</td>
<td>- Storm water (SW)</td>
</tr>
<tr>
<td>- Waste water (WW)</td>
<td>- Waste water (WW)</td>
</tr>
<tr>
<td>- Oil and gas (OG)</td>
<td>- Oil and gas (OG)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EX-CYCLONE GITA</th>
<th>MODEL IMPROVEMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete additional lifelines of interest and complete component component interdependency mapping</td>
<td></td>
</tr>
<tr>
<td>Complete multi-component failure analysis and criticality quantification</td>
<td></td>
</tr>
</tbody>
</table>

Portray correlation analysis between critical infrastructure model and volcanic failure catchments in the Taranaki region.