Tsunami Vulnerability Analysis

A GIS Approach for the City of Port Alberni

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Disclaimer

This report was created to fulfill course requirements at Simon Fraser University, BC, Canada. The Tsunami Vulnerability Consultant Group is not a real company. This report has been made by undergraduate students and should not be interpreted as expert opinion or be relied upon for truth or validity in any context.

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Introduction

This project was conducted by the Tsunami Vulnerability Consultant Group on behalf of the City of Port Alberni. The client requested information on the tsunami risk faced in Port Alberni based on road networks, elevation, population density, warning systems, and demographic attributes of the city. Another request was the recommended placement of two additional warning sirens to supplement the existing four. In consultation with the City, the Tsunami Vulnerability Consultant Group identified key analyses to be conducted and specific cartographic outputs to be produced.

Our scenario is an M9.0 subduction megathrust earthquake with waves arriving 5-60 minutes after shaking is felt. Tides and time of day are random and the largest wave is expected to cause run-ups of over 20m in depth. Bridges may or may not have been damaged during the earthquake which affects the road network analyses

At the client's request, we attempted to include socio-economic data but ultimately created our own index that is better supported in the literature. Due to the nature of subduction megathrust earthquakes, early warning systems are mostly ineffective because tsunamis would arrive well in advance of an official warning. Therefore, only sirens were incorporated into our analysis.

The following sections will first define risk and describe the nature of tsunamis. We will then provide an overview of tsunami risk culture and identify where our study fits within emergency management literature. This thorough background is necessary to contextualise our findings and aid in more informed decisions by local authorities.

Literature Review

Defining Risk

Defining risk, vulnerability, and hazards are important to reducing ambiguity and improving the quality and intelligibility of our analysis. Clague et al. (2003) note that risk is typically defined as the physical hazard multiplied by the social vulnerability. This study combines topographic features and knowledge of natural processes with demographic features and knowledge of how these are directly impacted by tsunamis. The literature defines vulnerability as the susceptibility of a community to a hazard (Hewitt 1997), the product of social behaviours, actions , and patterns (Wisner & Luce 1993), as functions of class, marginalisation, economic, and political powers (Susman, O'Keefe & Wisner 1983), or as the confluence of ecological, political, and developmental risks to humans (Blaikie & Brookfield 1987). Vulnerability is necessarily difficult to define because it is rooted in the specific experiences of people and varies across space and time. This is a relevant concern for tsunami studies that must synthesise data collected globally from the poorest villages of Indonesia to the most resilient beach towns of California. The specific vulnerabilities and risk factors used for this study are explained in detail later.

Defining Tsunamis

The Pacific coast of Vancouver Island is particularly susceptible to a large mega-thrust earthquake as well as the secondary effects of a tsunami or harbour wave (Clague, Munro & Murty 2003). Earthquakes are the source of 82.3% of the tsunamis in the Pacific Ocean and between 1861 and 1948, only 124 tsunamis were produced from over 15,000 earthquakes (Bryant 2008, p. 127). This study is concerned not just with earthquake-

generated tsunamis, but specifically with tsunamis generated from 'subduction megathrust earthquakes' with a moment magnitude exceeding M9.0. These seismic events have occurred twice in the past 1100 years (Koshimura et al. 2012) and would have dire consequences for coastal communities on the west coast of Vancouver Island (Clague, Munro & Murty 2003). Other sources of tsunamis such as landslides, volcanic eruptions, anthropogenic explosions, and meteor-strike events will not be directly addressed, though many of the findings presented will have relevance to other less severe tsunamis.*

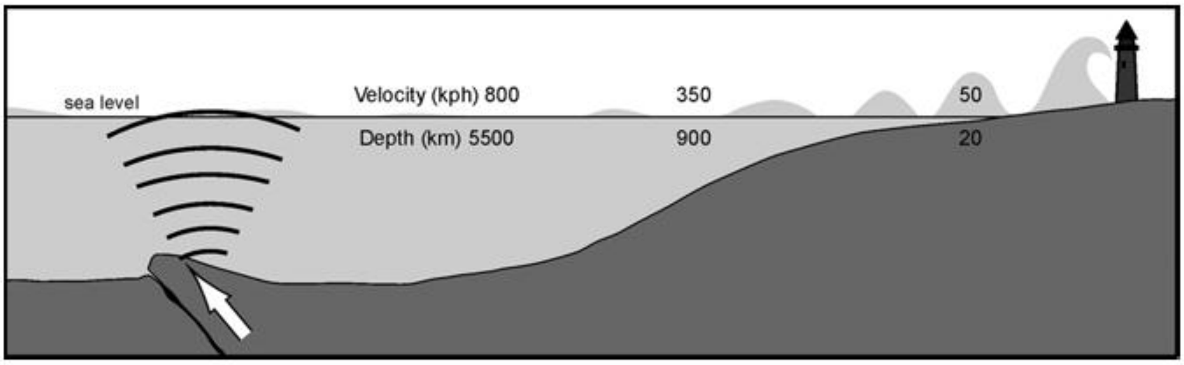

Figure 1: A large earthquake displaces the floor and produces a tsunami outward from the source. Waves increase in amplitude and slow as they approach land (Clague 2002).

Tsunamis have exceptionally long wavelengths relative to wind driven wave or swells and are generally undetectable in open ocean despite travelling at up to 800 km/hr. It is only when approaching shorelines that waves begin to increase in amplitude (Clague, Munro & Murty 2003). The recent 2011 Tōhoku earthquake and tsunami in Japan exhibited many of the same characteristics as our modelled scenario: a large magnitude seismic event near coastal communities resulting in highly variable shoreline effects ranging from benign to wide scale devastation. The delay between the earthquake and the arrival of the resultant tsunami in Japan was estimated at 40-60 minutes (Mas et al. 2012; Koshimura et al. 2012). A megathrust earthquake would likely give as little as 5-15 minutes of warning as Vancouver Island is closer to the boundary between tectonic plates (Emergency Info BC 2013; Clague, Munro & Murty 2003). Warning systems are most effective for tele-tsunamis, which are generated thousands of miles offshore and allow an evacuation to take place over many hours. Evacuation for local tsunamis, like the megathrust earthquake and tsunami, rely primarily on self-evacuation without warning from local authorities (Emergency Info BC 2013) as many Japanese communities did, though sirens may still be useful and are included in our analysis (Darienzo et al. 2005).

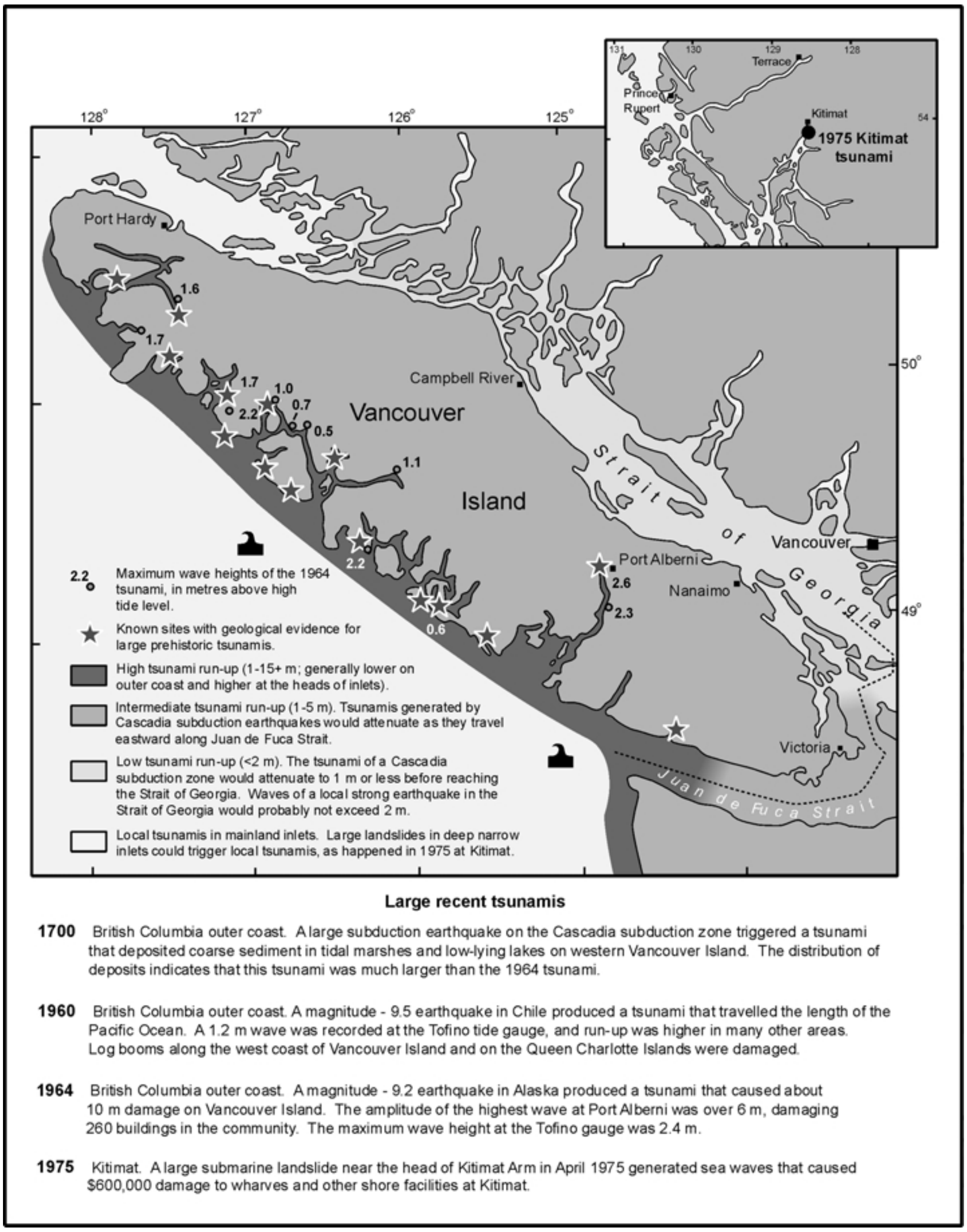

Figure 2: Tsunami hazard map of southwestern British Columbia showing maximum wave heights from the 1964 tsunami in Alaska (Clague, Bobrowsky & Hutchinson 2000)

Prediction and Evacuation

Tsunamis are secondary effects of earthquakes and therefore become more challenging to predict. Earthquakes are only estimated and expected for regions based on historical data and predicting tsunamis can only be done immediately following an earthquake. For the 2011 Tōhoku earthquake in Japan, the Pacific Tsunami Warning Centre issued a preliminary warning as soon as ten minutes after the initial earthquake (Stimpson 2011). It was noted that the Tōhoku earthquake was widely reported within three minutes of its occurrence and 90% of the town had begun evacuating within 30 minutes (the majority within 10 minutes) because "[They] thought a tsunami would come" or because someone had recommended they do so (Koshimura et al. 2012). Wave height predictions take at least 90 minutes (Wei et al. 2013). The importance of continual education and awareness efforts cannot be over-emphasised as these 'soft-measures' are the cheapest and most effective tools available for mitigating risk (Clague, Munro & Murty 2003; Supparsi et al. 2013). Coastal Japanese communities hold

Tsunami Festivals to maintain awareness and build memorials to tsunami victims to remind communities of previous run-up heights and that tsunami recurrence intervals often exceed a single human lifetime (Koshimura et al. 2012; Supparsi et al. 2013).

Emergency Management Literature and Our Study

Emergency Management literature promotes the idea of resilience, rather than just vulnerability. It is a much more comprehensive and proactive approach that incorporates land-use planning, inter-governmental collaboration, consensus-based mitigation plans, and educational efforts (González et al. 2005; Jonientz-Trisler et al. 2005; Dengler 2005; Eisner 2005). Our study aims to support some of these efforts by identifying vulnerable populations, defining areas of safety and areas of risk, providing multiple evacuation scenarios for road networks, and suggesting locations for additional siren placement to ensure adequate coverage of the Port Alberni area. Our analyses are not prescriptive by any means, as local authorities understand the issues and area in far greater depth than a GIS analysis can provide. However, inundation maps are very useful tools for disseminating disaster information (Eisner 2005) and regular testing of sirens and educational tools helps build awareness and familiarity with the risk that is often unknowingly carried by residents and visitors to an area (Dengler 2005; Johnston et al. 2005).

Study Area

Port Alberni is a town of about 35,000, 100km inland from the west coast of Vancouver Island. It is served primarily by an east-west running provincial highway. It is located at the river delta of the Somas River at the end of the narrow Alberni Inlet. It has a coastal geometry that amplifies and funnels tsunami energy further inland resulting in more severe run up effects (Supparsi et al. 2013; Clague, Munro & Murty 2003). In Japan, similar complex waterways show the highest recorded run up reaching up to 38.2m above sea level (Koshimura et al. 2012). The flatter Sendai Plain experienced run-ups of between 5m and 19.5m and horizontal extent of 5km (Nandasena, Sasaki & Tanaka 2012; Koshimura et al. 2012). The 20m inundation zone used in earlier Port Alberni planning is therefore a conservative estimate with 30m being a likely.

There are many industrial activities near the water such as sewage treatment, paper processing, and fishing, which pose a risk (Yeh, Sato & Tajima 2013) but are not included in our analysis. There are several Indian Reservations located throughout the study area that withhold statistical data and cannot be included in our analysis directly.

Methods

Topographic Analysis

Topographic risk is an integral part to any vulnerability assessment regarding natural hazards and disasters. In particular, when conducting a vulnerability assessment for tsunamis, it is essential to determine the areas that would be more likely to be physically affected by incoming waves. For our assessment, the region of Port Alberni, Alberni Inlet, and Somas River were analysed using digital elevation models (DEMs) to classify four distinct sources of risk and combine them to create a final topographic vulnerability assessment map (Figure 13). These four factors are elevation, aspect, slope, and coastal proximity, and were decided upon from literature review of past tsunami risk assessments, with the most substantial influence coming from Sinaga's 2011 paper on tsunami vulnerability in Indonesia.

The data utilized to determine topographic vulnerability was collected from the Spatial Information Systems lab data warehouse at Simon Fraser University, and the ABACUS data sets through the British Columbia Research Libraries' Data Services. Lakes and rivers were found from the SFU warehouse, and the DEMs were found through ABACUS. Four DEMs were collected in order to achieve our study area. These were parts 2, 3, 6, and 7 from area 93f with a 30-meter resolution and in ASCII format. Therefore, the DEMs had to be converted to raster from ASCII using the ASCII to Raster tool in ArcMap. All the data collected was then projected in the coordinate system of NAD 1983 UTM Zone 10N, the four DEMs were stitched together using the Mosaic to New Raster tool in ArcMap, and the resulting Raster was resized to our study area using the clip function.*

*Elevation was then reclassed from the final DEM raster based on values obtained from literature review with a macro-modeller to allow quick changes later on should the model require recalibration. This reclassification aimed to take the values of elevation and change them into five standardized categories of risk. The original elevation reclass was five categories of risk (5 being high, and 1 being low), each raising 5 meters from sea level, until the last included 20 meters and beyond. This was based on similar values within the Sinaga 2011 study. However, these were determined to be unsuitable since we wanted to portray a worst-case scenario and match historical indications of potential 20-meter inundation from almost 20-meter high tsunami waves (Clague 2000, p. 854). The reclassification was then altered to having 0-20 meters being the highest risk area and then decreased risk in increments of 5 meters from there (Figure 3). A similar process was carried out for Aspect and Slope once they were created using the Aspect and Slope Spatial Analyst Tools respectively using literature review as backup for the rationale behind the reclassifications (Sinaga et al. 2011)).

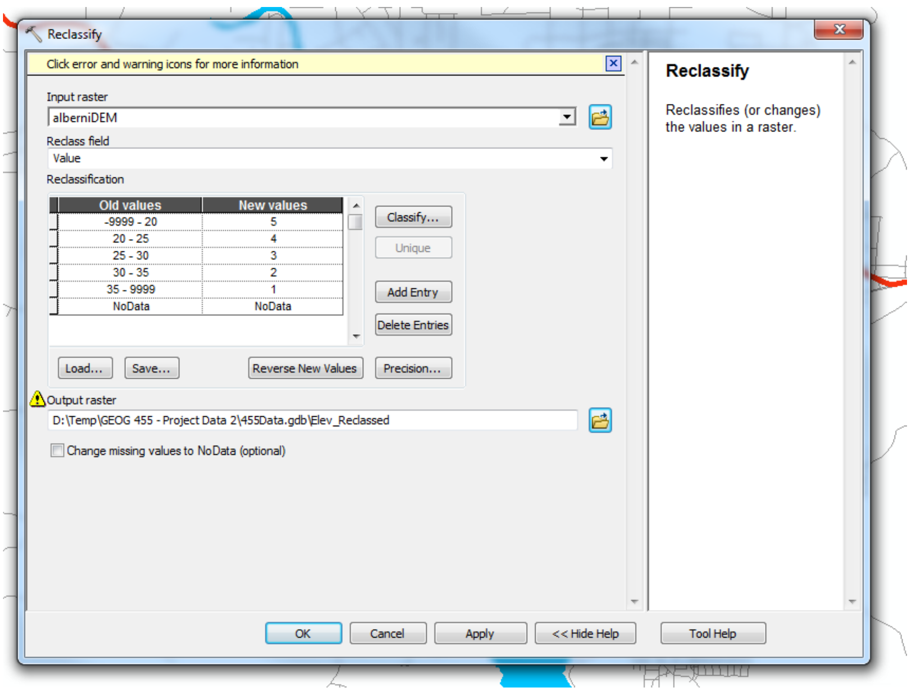

Figure 3: Reclassification of elevation into five categories of risk.

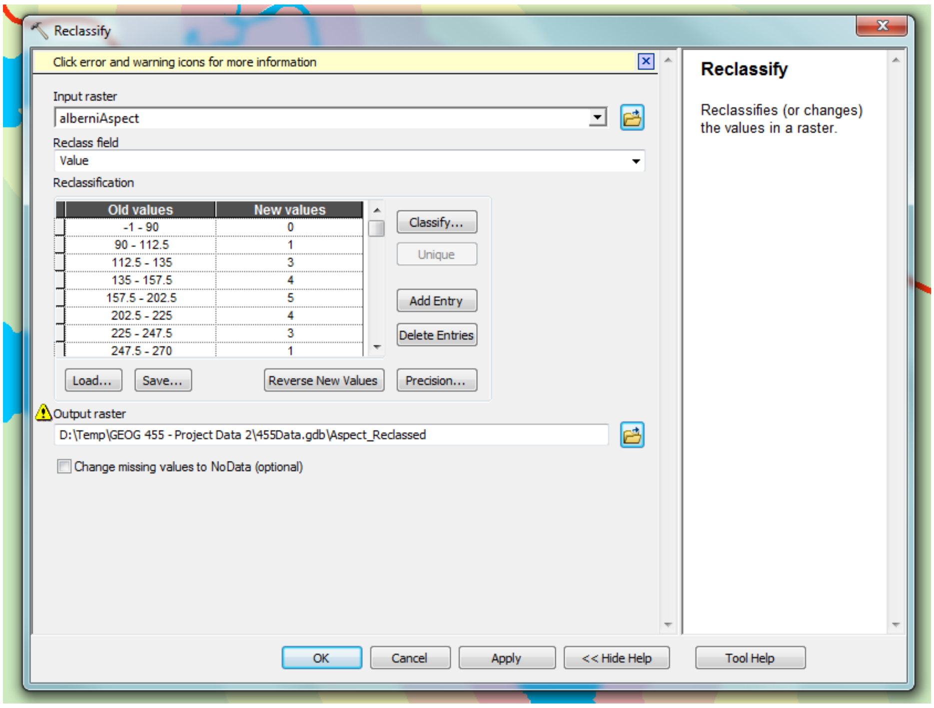

Figure 4: Reclassification of Aspect based on degree direction (0 degree being North) into five categories of risk. Slopes facing south received a higher score (more risk) than slopes facing north, east, or west.

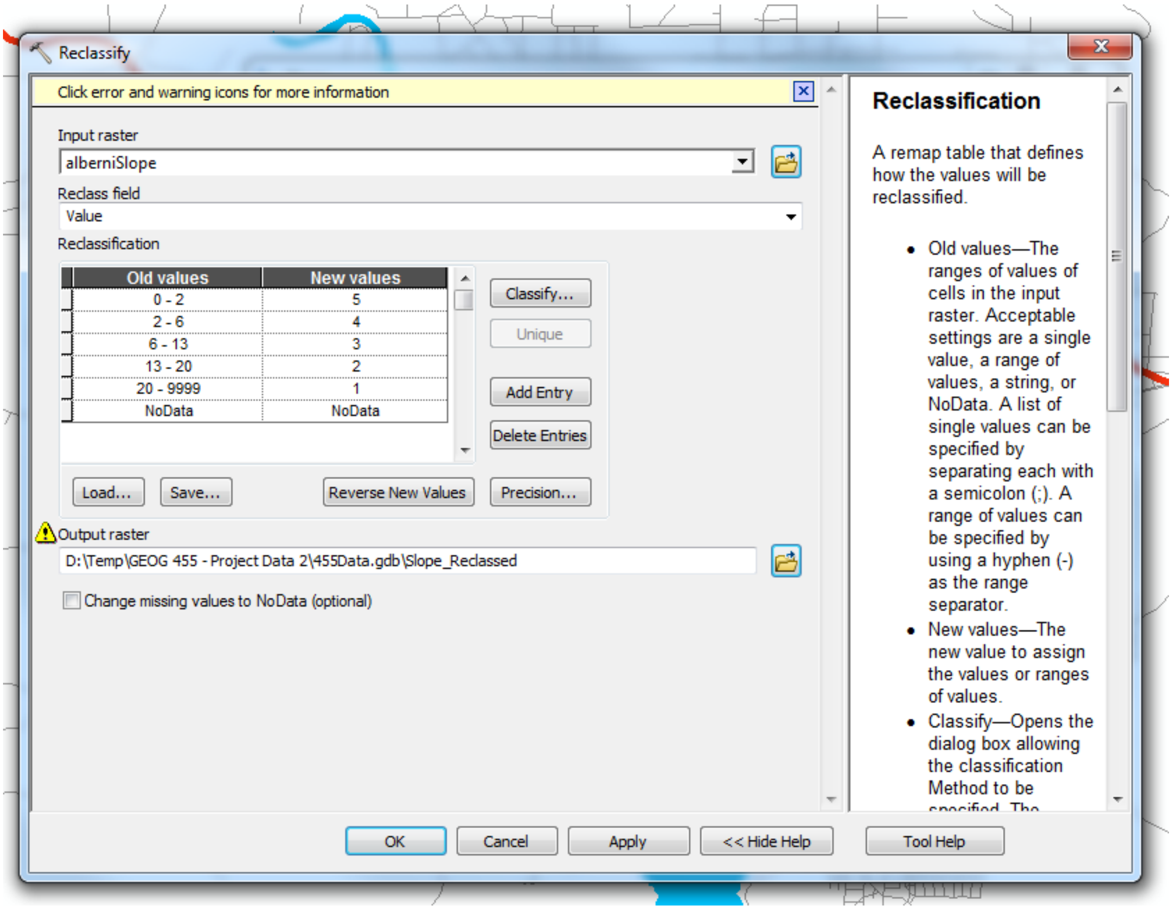

Figure 5: Reclassification of Slope into five categories of risk.

Coastal Proximity was obtained by generating a buffer zone around the coastline and the Somas River. To do this, the Somas River and Alberni Inlet were selected and merged into one layer without analysing adjacent bodies of water unaffected by the tsunami (i.e. lakes). Various distances separated into five levels of risk (much like the other factors) from the coastline and river were then buffered and joined to form a multiple ring buffer (Figure 6). This was done through a complicated macro model (Figure 7). Prior to the final process of weighted overlay of the four factors, the coastal proximity layer had to be converted to raster. This was done by converting the selected feature class to a shape file before converting it to raster by a Polygon to Raster conversion tool in Arc Map.

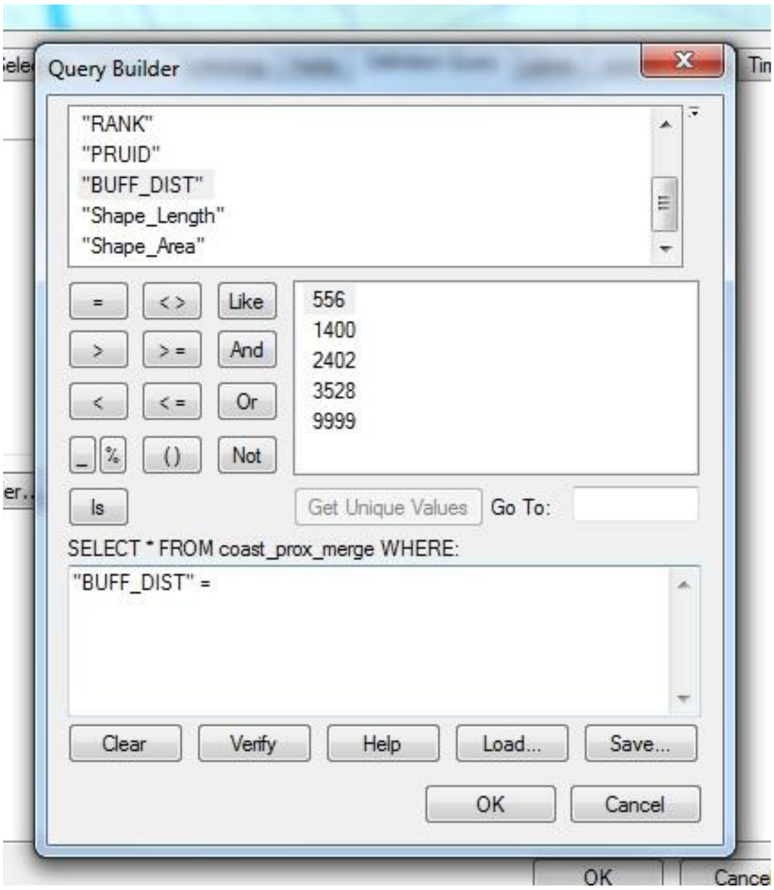

Figure 6: The five classifications of risk for coastal proximity. The numerical values represent the limits that each buffer covers in meters from shore, with the risk being highest in the 0-556 meter buffer and decreasing from there.

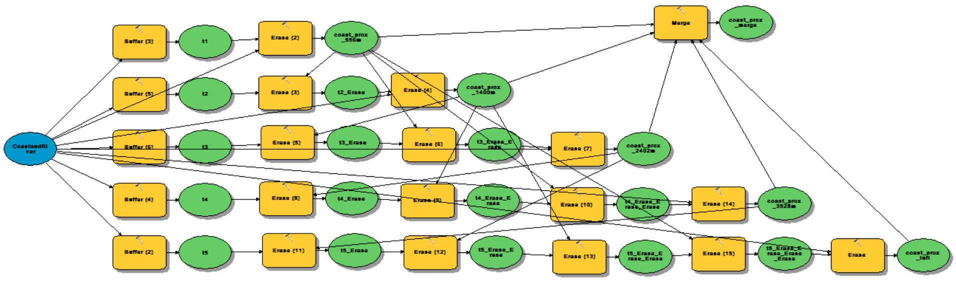

Figure 7: Macro Model to generate multiple ring buffers.

Finally, the four factors of Elevation, Aspect, Slope, and Coastal Proximity were combined using the Weighted Overlay tool in ArcMap that allows the user to assign specific weights to each factor, causing some factors to be favoured more than others do in the final analysis (Table). The weighted overlay was ran twice, since the first weightings resulted in a product which did not match historical inundations very well due to aspect being favoured too highly within the analysis. This was accounted for and fixed with the second weighted overlay.

Table 1: Original Weightings based off Sinaga 2011 study, while final weightings take into historical data into account (See Figure 8)

Factor	*Original Weighting*	*Final Weighting*
Elevation	*43%*	*47%*
Aspect	*17%*	*10%*
Slope	*25%*	*27%*
Coastal Proximity	*15%*	*16%*

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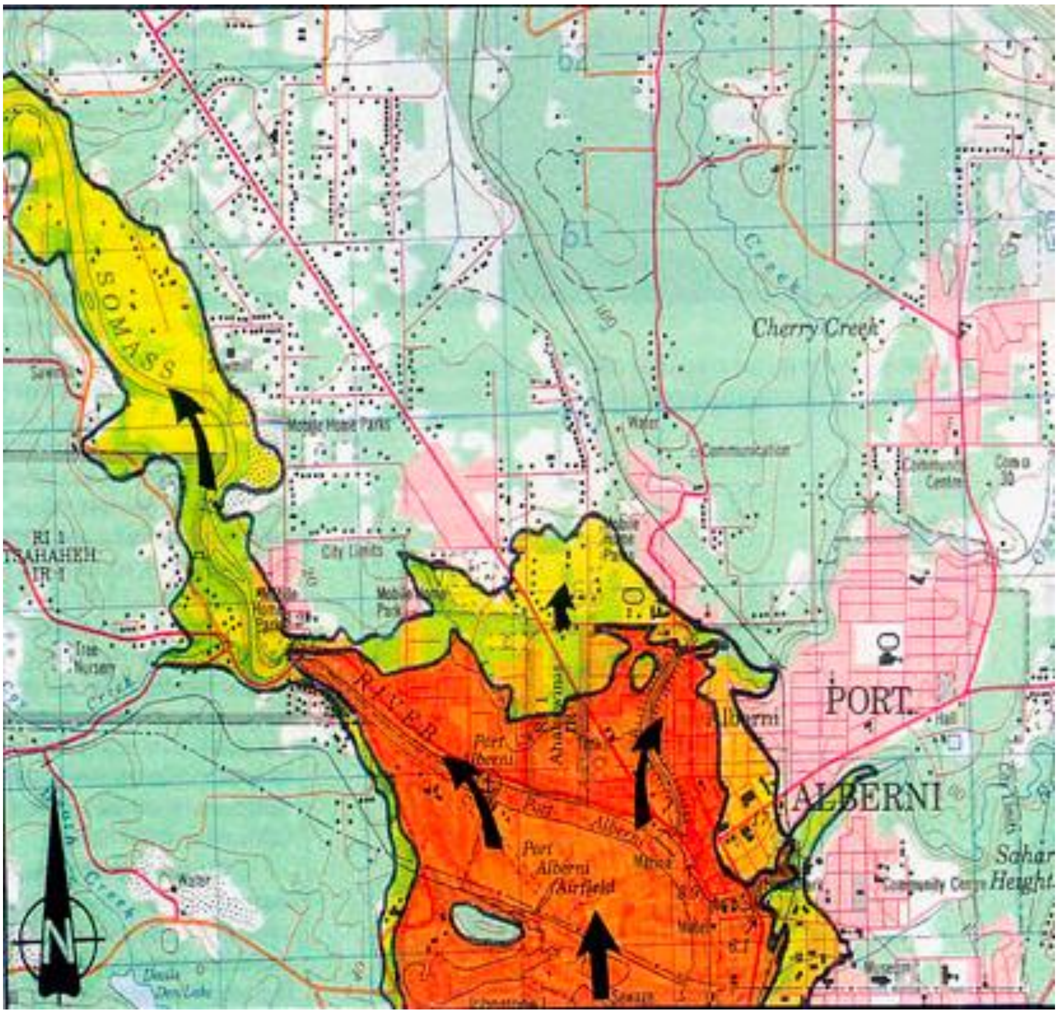

Figure 8: Historical Inundation of Port Alberni. Orange from the 1964 Tsunami, and Yellow + Orange determined from historical data of a tsunami that occurred in 1700 with a maximum wave height of 16 meters (Clague 2000, p. 854).

Vulnerability Analysis

An operational definition for social vulnerability in this study will be the relative exposure of the population for a given risk factor as a percentage of the total population. The social vulnerability index will be constructed by taking the sum of each of these percentage points and dividing them by the total number of risk factors. The index does not consider post-tsunami vulnerabilities such as ability to recover or the need for more long-term sheltering as this is beyond the scope of the study. This method has been adapted based on a 2013 report by the USGS (United States Geological Survey 2013) which argues that inferring actual causal relationships between risk factors and tsunami mortality and injury would invite undue speculation. This method is descriptive and avoids misrepresenting vulnerability through unsubstantiated and unduly subjective factor weightings. The USGS report explains:

"Parsing out individual demographic attributes provides some insight in evacuation challenges, but it is somewhat simplistic because individuals and the communities they live in are not one-dimensional. For example: renters, small children, and or non-English-speaking residents all present evacuation challenges on their own and these difficulties are compounded when all three attributes are found in the same neighbourhood." (United States Geological Survey 2013)

This descriptive method relies on counting residents multiple times rather than a statistical approach that identifies independent variables with no collinearity. The vulnerability index used offers an analytical visualisation of data to be interpreted by local emergency planners.

Data Overview

Data for the vulnerability index were sourced from 2006 Census data from Statistics Canada (Statistics Canada 2007) using all available dissemination areas for the Alberni-Clayoquot census division. Each dissemination area (DA) was checked for a corresponding DA polygon within the ArcGIS project and superfluous data was discarded so that each DA polygon had only one corresponding row of census data. Populations for each DA ranged between 400 and 600 with some outliers.

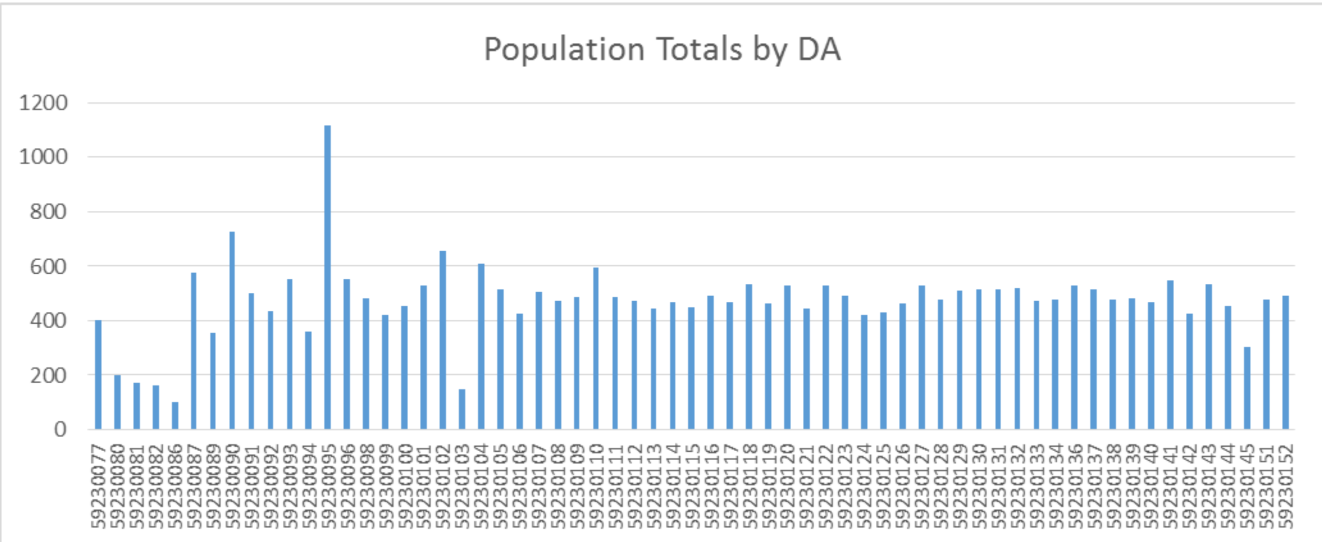

Figure 9: Population counts for all DAs used for the study.

Data analysis happened within an Excel spreadsheet and the final vulnerability values were manually added to the ArcGIS project. Port Alberni has several Indian Reserves (IRs) that are not covered by the dataset available and have not been included in the analysis.

Calculation of Vulnerability Index

The vulnerability index itself is calculated for each DA as follows:

$$\frac{\sum_{i=1}^{n} \frac{\text{residents meeting factor criterion } i}{m}}{n}$$

where $n =$ the number of risk factors

where $m =$ the population total for a given DA

For example, if 30 out of 300 people of a DA meet a specified criterion, that factor for the DA will have a value of 10. For another criterion, if 3 people out of 300 match the criteria, that factor for the DA will have a value of 1. The sum of the percentage points (11) is divided by the total number of risk factors (2) and the DA would have a score of 5.5 or 0.055. This value is now normalised and can be compared against other DAs that have been calculated in the same way.

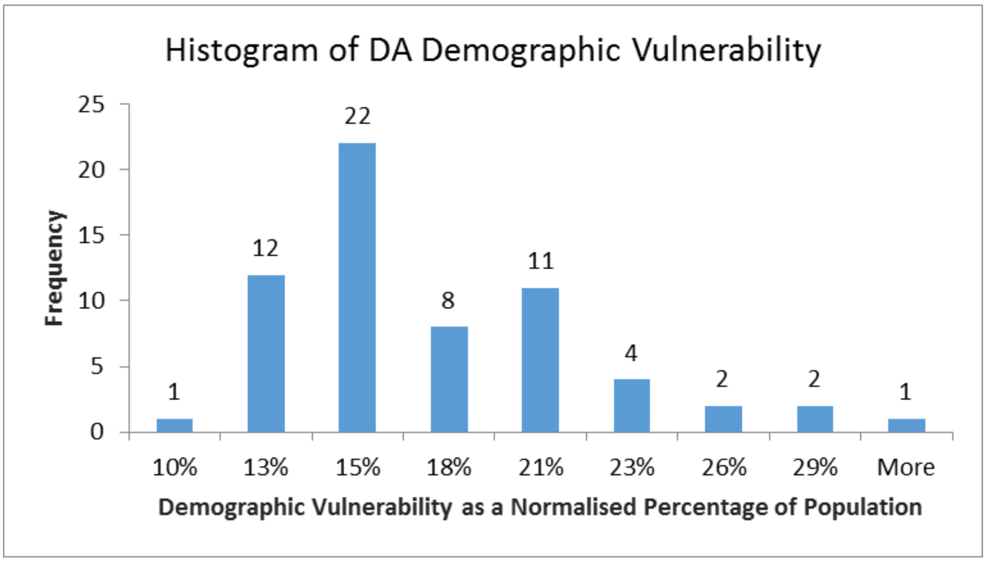

Figure 10: Frequency of vulnerability percentages of all DAs.

The figure above shows the distribution of vulnerability index scores and it is evident that the majority of DAs within Port Alberni have less than 20% of their population identified as higher-than-normal vulnerability. A score of 0% would mean that no residents fit any of the criteria to be classified as part of the risk factors (i.e. wealthy, a long-time resident, a homeowner, and so on). Some risk factors are mutually exclusive (one cannot be a single mother and live alone, or be both under 15 and over 50 years of age) so there is an upper limit to this score.

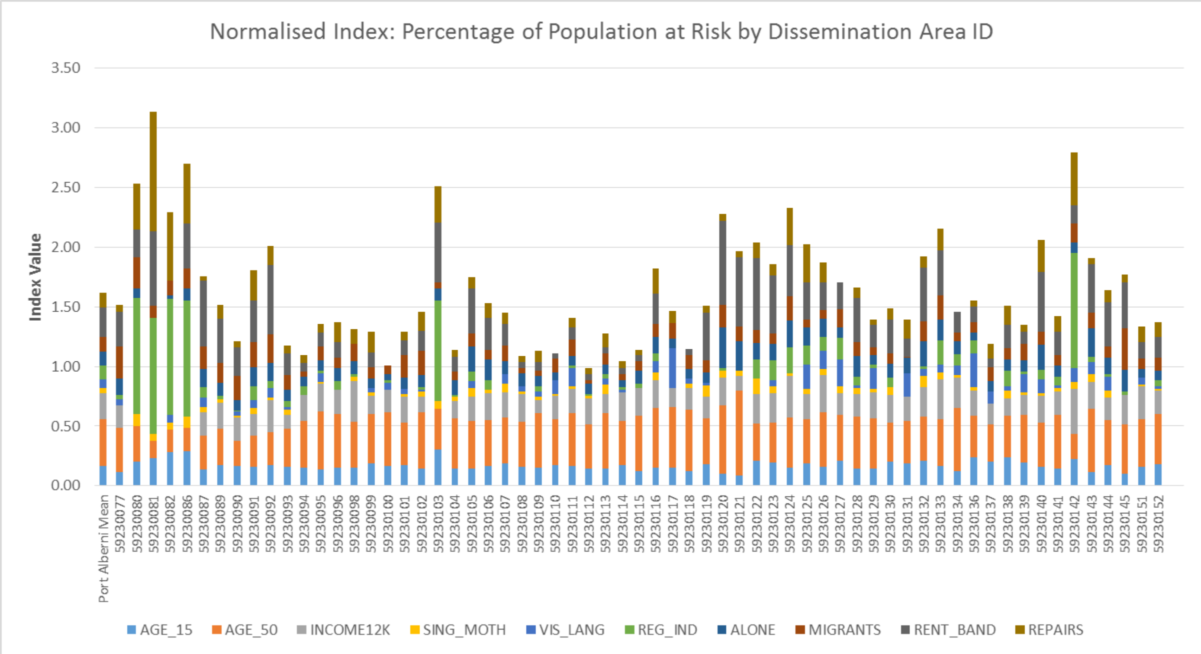

Figure 11: Graph showing the relative vulnerability of each DA and the factors that contribute to their level of exposure to the tsunami hazard.

The figure above shows the composition of vulnerability as it varies across space. This is detail not visible in the final map output but may prove useful in identifying specific needs of communities based on the more generalised final vulnerability map.

Risk Factors

A summary of all ten factors, possible explanations, and relevant academic references is below in Table 2. The following sub-headings will explain each risk factor's calculation in detail.

Table 2: Summary of individual risk factors used for the vulnerability index and possible reasons for their correlation in mortality and injury statistics as represented in the literature.

Risk Factor	*Possible Causes for Increased Risk Mortality and Injury Correlation*	*Supporting Sources*
Age > 50	*Physical limitations, reluctance to evacuate, health complications*	*Steckley & Doberstein 2011; United States Geological Survey 2013; Guha-Sapir et al. 2006; Doocy, Daniels & Kirsch 2013; Nishikiori et al. 2006; Nakahara & Ichikawa 2013; Koshimura et al. 2012*
Age < 15	*Unable to self-evacuate, failure to understand sirens, inability to swim*	*Steckley & Doberstein 2011; Guha-Sapir et al. 2006; Doocy, Daniels & Kirsch 2013; Nishikiori et al. 2006; Nakahara & Ichikawa 2013*
Income < 12,000	*No vehicle access for evacuation, no mobile phone or radio for warnings, reduced capacity to prepare for tsunami*	*Steckley & Doberstein 2011*
Single Female Parent	*Children may need to be collected from home or institutional settings (day-care, school, etc.), slower to evacuate with dependents*	*Steckley & Doberstein 2011; United States Geological Survey 2013; Fulu 2007; Guha-Sapir et al. 2006; Doocy, Daniels & Kirsch 2013; Frankenburg et al. 2011*
Visible Minority/ Language Barrier	*Educational materials may be presented in a culturally or linguistically challenging way, reduced community engagement leading to reduced awareness of tsunami hazard*	*United States Geological Survey 2013*
Registered Indian	*Different risk culture leading to alternative interpretation of typical educational materials and warnings, institutional marginalisation that exacerbates other risk factors described*	*Steckley & Doberstein 2011*
Single Occupancy	*Reduced preparation for tsunami due to sense of risk controllability, less likely to learn of tsunami through household, tsunami warnings more likely to reach a larger household*	*Guha-Sapir et al. 2006*

New Resident	*Unfamiliarity with tsunami hazard, reduced knowledge of road networks and safe areas, fewer social connections and opportunities for increasing awareness of tsunami hazard*	*United States Geological Survey 2013*
Rental/Band Housing	*Reduced incentives to invest in property lead to reduced preparation, more likely located in multi-unit housing at greater risk for earthquake damage, preparation and education aimed at home-owners*	*United States Geological Survey 2013*
Weakened Structure	*Housing built according to older building codes is more susceptible to earthquake damage, buildings requiring major repairs are more likely to fail against a tsunami wave*	*Steckley & Doberstein 2011; Gokon & Koshimura 2012; Guha-Sapir et al. 2006; Frankenburg et al. 2011; Nishikiori et al. 2006; Yeh, Sato & Tajima 2013; Nandasena, Sasaki & Tanaka 2012*

Age

The first age factor was calculated by summing Male 0-5, 5-9, and 10-14 totals with Female 0-5, 5-9, 10-15 totals, and dividing by the total population. The second age factor was done by summing Male and Female totals in 5-year increments from 50 and dividing by the total population.

Income

Canada does not have an official definition of poverty and Statistics Canada does is not in a position to make such a political decision (Statistics Canada 2007). In lieu of such data, $12,000 in after-tax annual income is an estimate made to represent 'low income' individuals; however, such an assumption is recognised as entirely subjective. It is calculated as the sum of all individuals with or without declared income up to $11,999 and then divided by the total population. Households with more than one income could therefore have an income higher than $12,000 if there are multiple earners and still be classified as 'low income'.

Single Female Parent

Children have already been accounted for above; therefore, the 'Total lone-parent families – female' attribute can be divided by the total population.

Visible Minorities, Registered Indians, and Non-English Speakers

Speakers of non-English languages and total visible minorities each have their own totals. These are summed and divided by the total population. There is also an attribute for 'Registered Indians' which is divided against total population.

Migrants

Migrants are defined as the average number of individuals that have moved into the area between 1 and 5 years ago, then divided by the total population.

Rental and Band Housing, and Housing Quality

The sum of housing units identified as rental or band housing was summed and divided by the total number of occupied private dwellings. This does not take into account the number of residents within a dwelling. The attribute identifying occupied private dwellings requiring major repairs is used as a proxy for identifying DAs that may be structurally un-sound and at greater risk to earthquake and tsunami damage. This number is divided by the total number of occupied dwellings for which there is data on housing quality.

Network Analysis

It was important to not only include topographic and demographic data in the tsunami vulnerability assessment of Port Alberni in order to determine two possible new locations for warning sirens, but to also incorporate a network analysis. The reason for this is that it is important to know how long it should take an individual to drive to safe zones within the city since a locally caused tsunami would likely strike within less than 30 minutes (Clague 2000, p. 859). However, it is not good enough to run a standard analysis since emergency services would need information regarding travel time throughout the city after waves have potentially destroyed any major bridges. Therefore, included within this assessment are two network analyses: one for before the tsunami hits, and one for after, taking into account potential damages.

A British Columbia road data (shape file) from 2013, from the Simon Fraser University Data Warehouse in the Spatial Information Systems computer lab were used for the analyses. A network dataset had to be created with ESRI ArcMap. By doing so, a connectivity model is created based off of the original data that can be used to run various transportation analyses with different factors incorporated such as driving distance, driving time, elevation, barriers, and factors. For this assessment, it was important to make sure that driving time was included within the dataset in order to determine the driving times within the city to various safe points. This was done by joining the network dataset to the time data fields within the initial road data. After the completion of the network dataset, the service areas analysis function was chosen, which determines polygons surrounding selected points based upon a chosen factor, which in our case was driving time.

When choosing the safe points for the analysis, our topographic vulnerability final product was consulted, as well as Google maps. By comparing our topographic vulnerability map to Port Alberni in Google maps, we were able to choose four safety points based on low vulnerability, and infrastructure in those areas that can support a large group of people. These points are the Eric J Dunn Middle School, Chamber of Commerce, Port Alberni Christian School, and one area on the west side of town which has many different services, including a bank, gas station, and parking lot. With the safety points chosen, the network analysis was run with the impedance set to driving time, polygons set so that there is no overlap and with default polygon breaks of 5, 10, 15, and 20-minute drive times. These times were chosen to both generate a nice visual, as well as to incorporate the fact that a locally generated tsunami could strike within minutes (Clague 2002, p. 23). As mentioned before, the analysis was run twice; one with all routes in tact to simulate before tsunami conditions, and one with major bridges set as barriers to simulate after waves hit and the potential damages they could cause.

Data Fusion

For the final vulnerability assessment of Port Alberni, the topographic and demographic data were combined to create a final map. To do so, we consulted with our advisor, Dr. John Clague as to how this could be *accomplished with the most accurate solution presented. Dr. Clague then suggested we take the topographic and demographic vulnerabilities and subject them to a range of weighted overlays. This way a range of extremes can be delivered to the client and they could interpret each as they wish. This was ultimately achieved by first converting the demographic vulnerability map to a raster file by creating a shape file layer based on the feature with the Feature Class to Shape File tool, and then converted to raster using the Polygon to Raster tool in ArcMap. Then the two final vulnerabilities were combined using weighted overlay in the macro modeller in ArcMap (Figure 12). Including the separate topographic and demographic assessments, there were three weightings - 25:75, 50:50, and 75:25. In other words, the results would end up showing a map where there is equal influence given to topographic and demographic, a map where topographic data has more influence over demographic data and vice versa, and the original maps where either component has complete influence.*

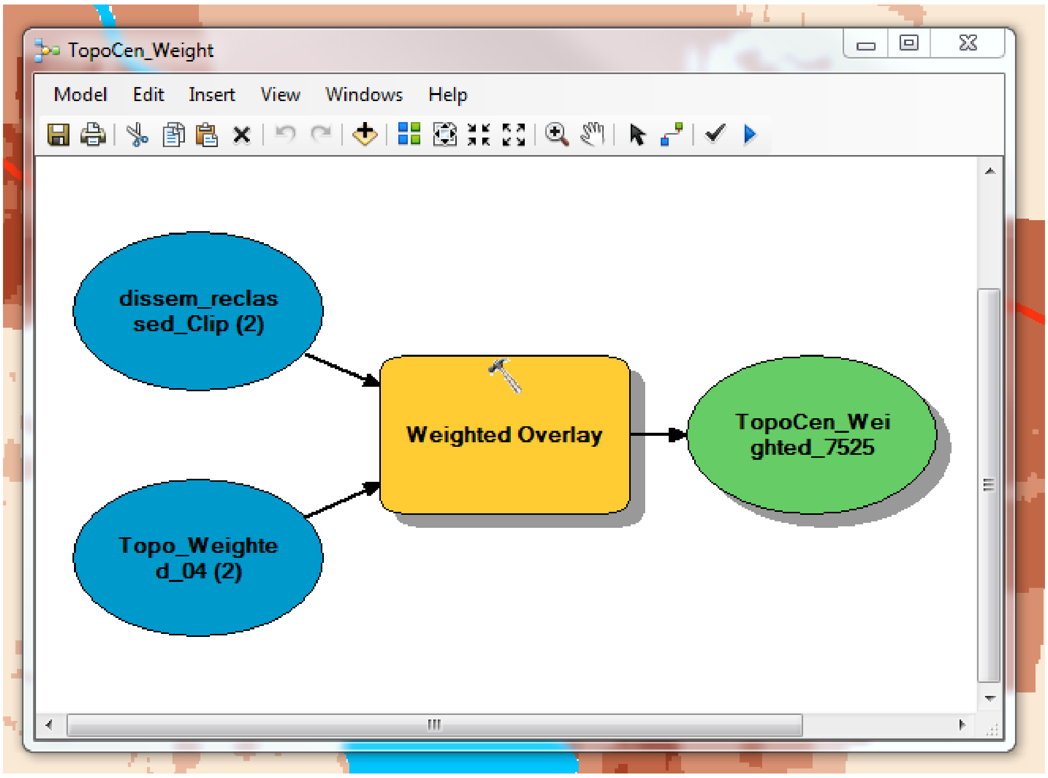

Figure 12: Macro Modeller of the weighted overlay of topographic and demographic vulnerabilities.

Warning Sirens

In order to gain perspective on where two new warning sirens could be placed, placing the four existing sirens in Port Alberni on our maps was necessary. When the city was contacted, there was no data as to an exact geometric location, and digitizing from a paper map could result in too much error. Therefore, we used a map created by the city that has the locations of the four sirens on it, and used the roads as reference. Then by locating the same roads closest to the sirens on our road data, we created point data to represent them. As a result, we would most likely be accurate within a few meters rather than going through a needlessly tedious digitizing process. Finally, by looking at the current locations of sirens over top of our vulnerability assessment, we were able to determine two new locations for sirens based on areas with no siren coverage and level of vulnerability.

Results

Topographic Map

The topographic map layer clearly shows a moderate hazard along the eastern slopes and the majority of hazard is the low-lying area directly north of the inlet. This map also improves upon existing sources by showing the hazard on the Somas and Stamp river systems further upstream.

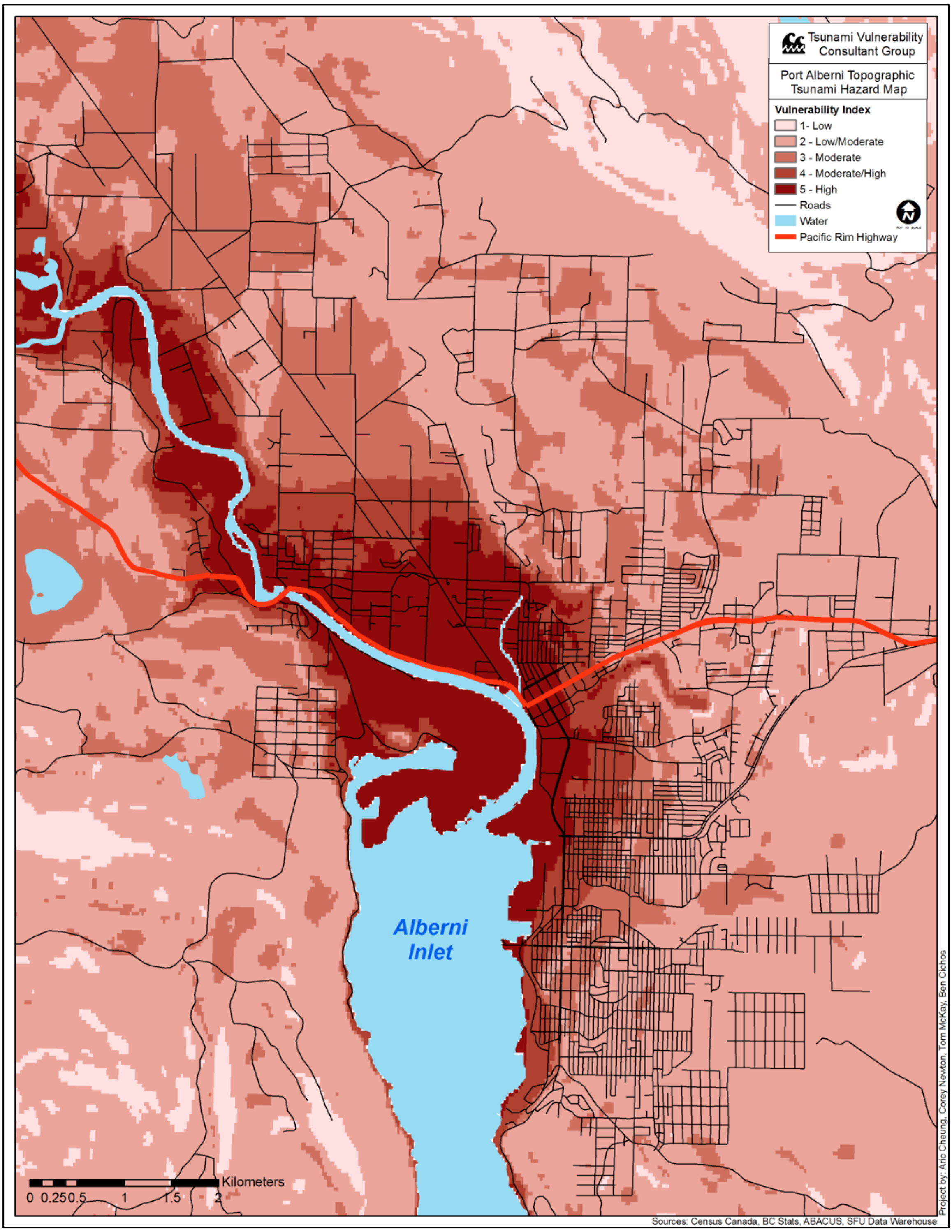

Figure 13: Topographic Result

Demographic Map

The social vulnerability map highlights areas near the east slopes along with high risk areas directly north of the inlet and along the Somas River. An Indian Reservation lies adjacent to the the high-risk DA in the north and erroneously has a 'low' vulnerability associated.

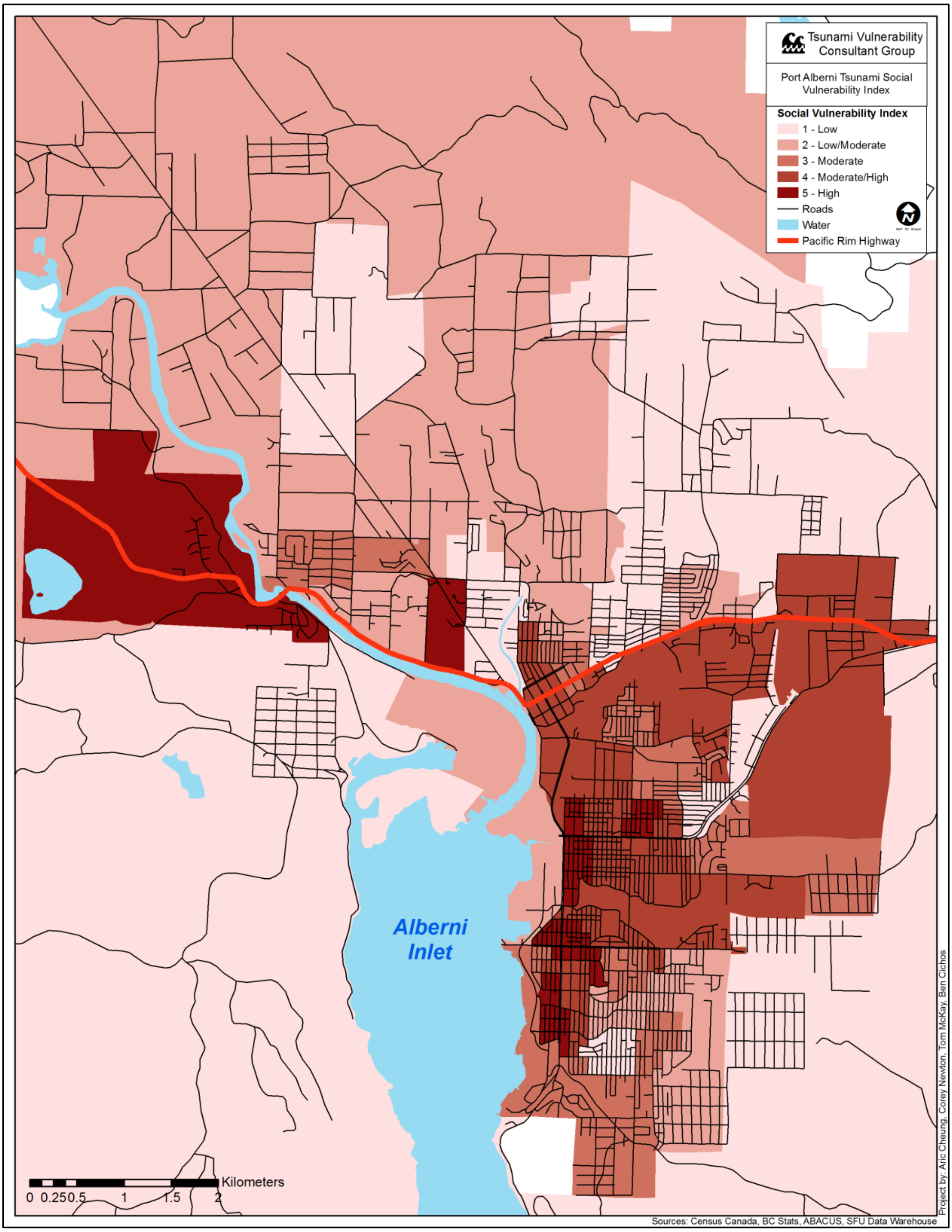

Figure 14: Demographic Result

Composite Maps

The results of these composite maps are subject to individual interpretation. Based on our understanding of tsunami behavior, we expect that the 75% Topographic map (Figure 17) will best represent the real risk to communities because the inundation will be relatively uniform and differences between DAs will likely be significantly reduced.

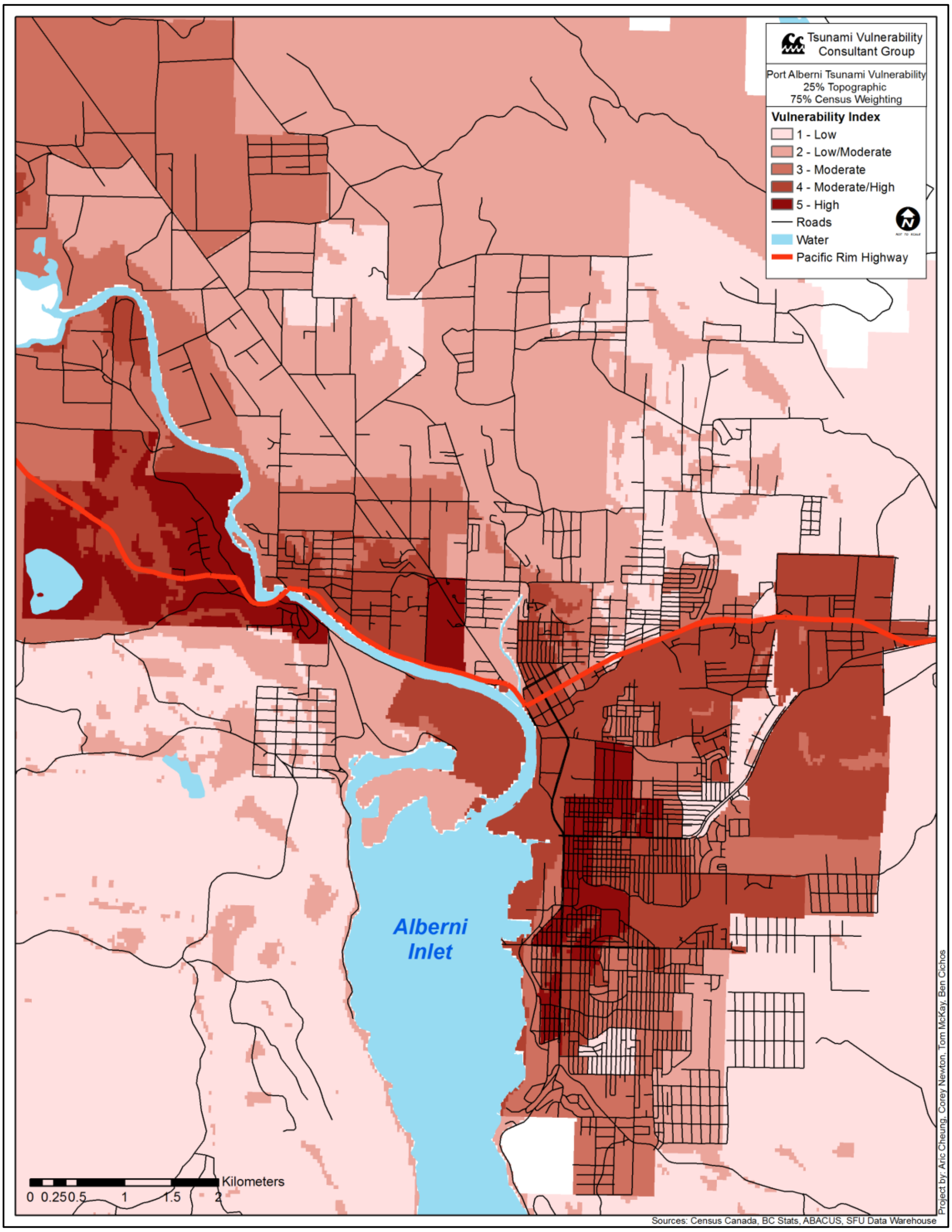

Figure 15: Composite Result: 25/75

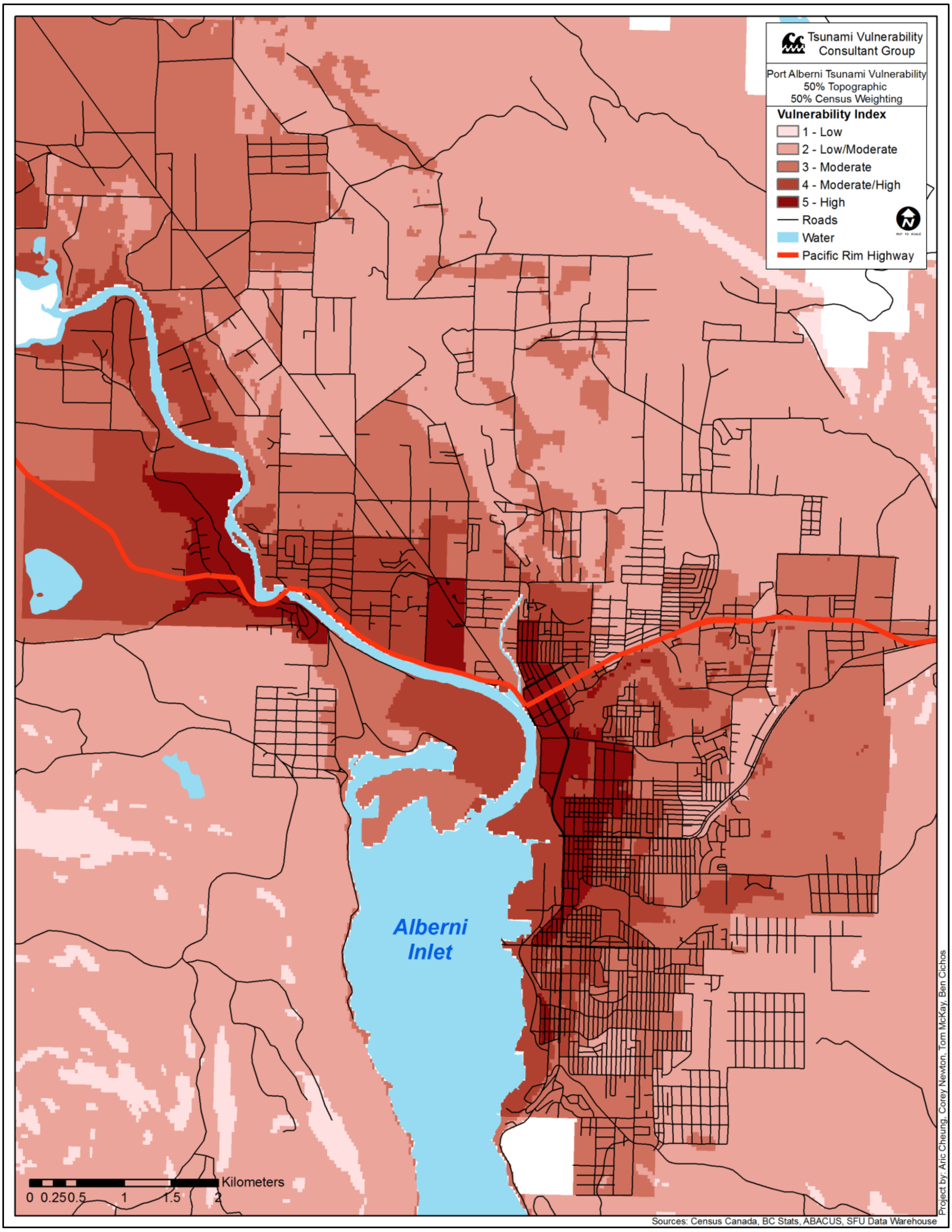

Figure 16: Composite Result: 50/50

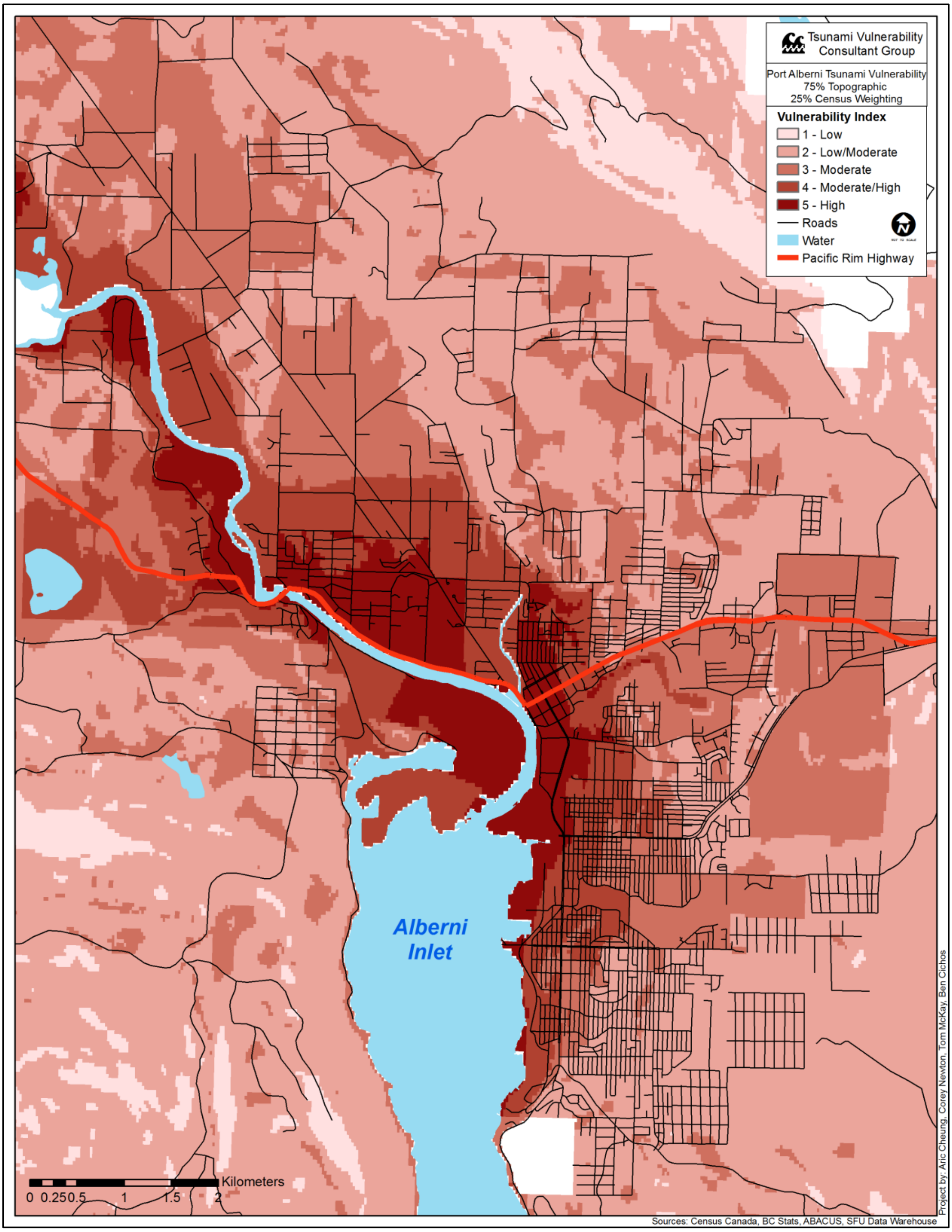

Figure 17: Composite Result: 75/25

Network Analysis

The figure below shows polygons of drive times to safe points. Conducting a evacuation route analysis is not possible in practice because it would assume that all residents were home during an earthquake and would leave immediately. This is especially difficult to do for a small area as generalisations can be made for much larger scenarios. Our scenario assumes that bridges have been damaged and are unusable for evacuation purposes. A safe point to the northwest of Port Alberni would reduce the evacuation time substantially for some residents.

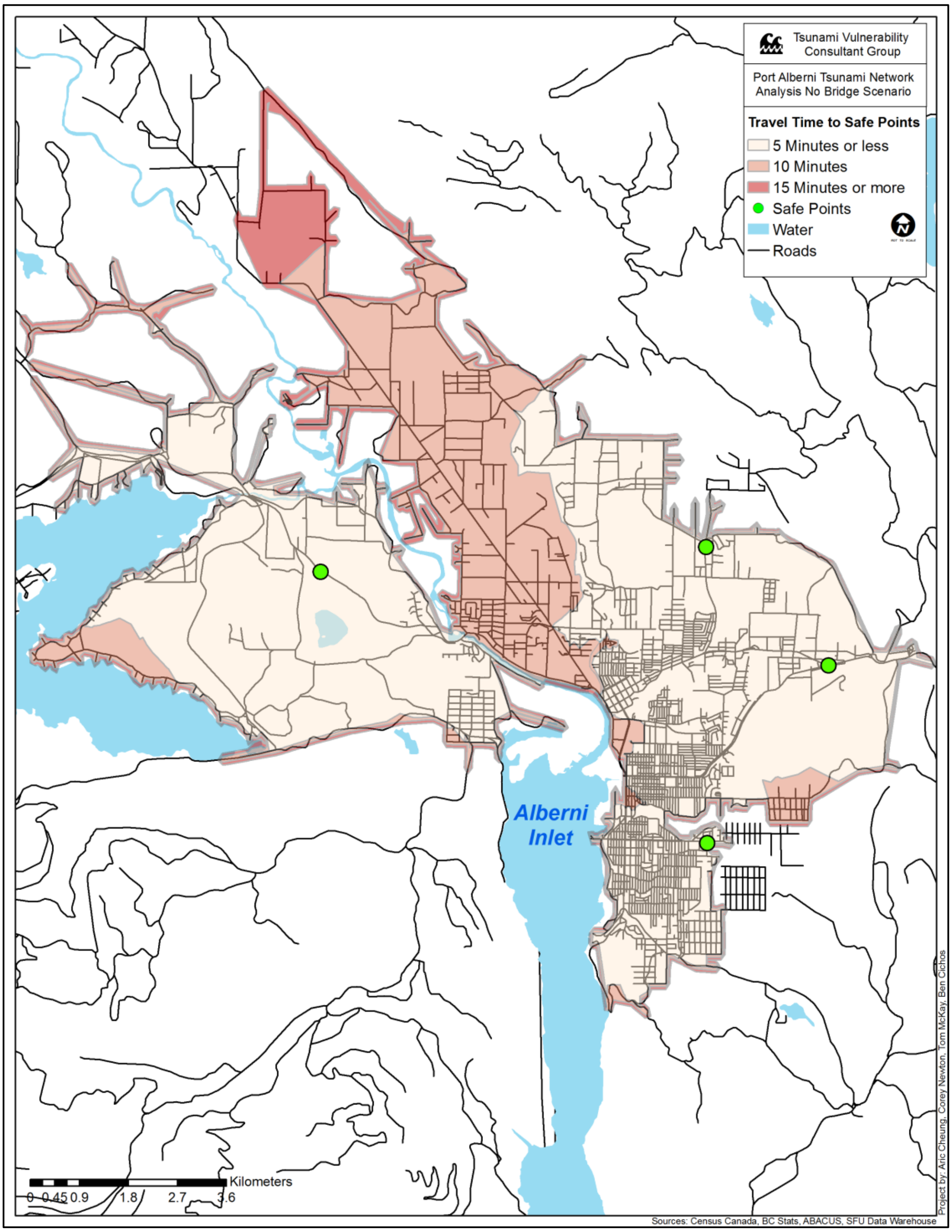

Figure 18: Network Analysis Result

Siren Result

We have located our recommended siren placements below. The southern siren was chosen on the basis that nearby residents had reported not hearing the sirens to the north of the river. The siren would also be located on a hill and less likely to be damaged. The siren towards the north-west should provide coverage for most of the river and is centred on the DA that appears to be facing the greatest risk overall. It is located on a higher elevation point as well, though this is not visible on the map.

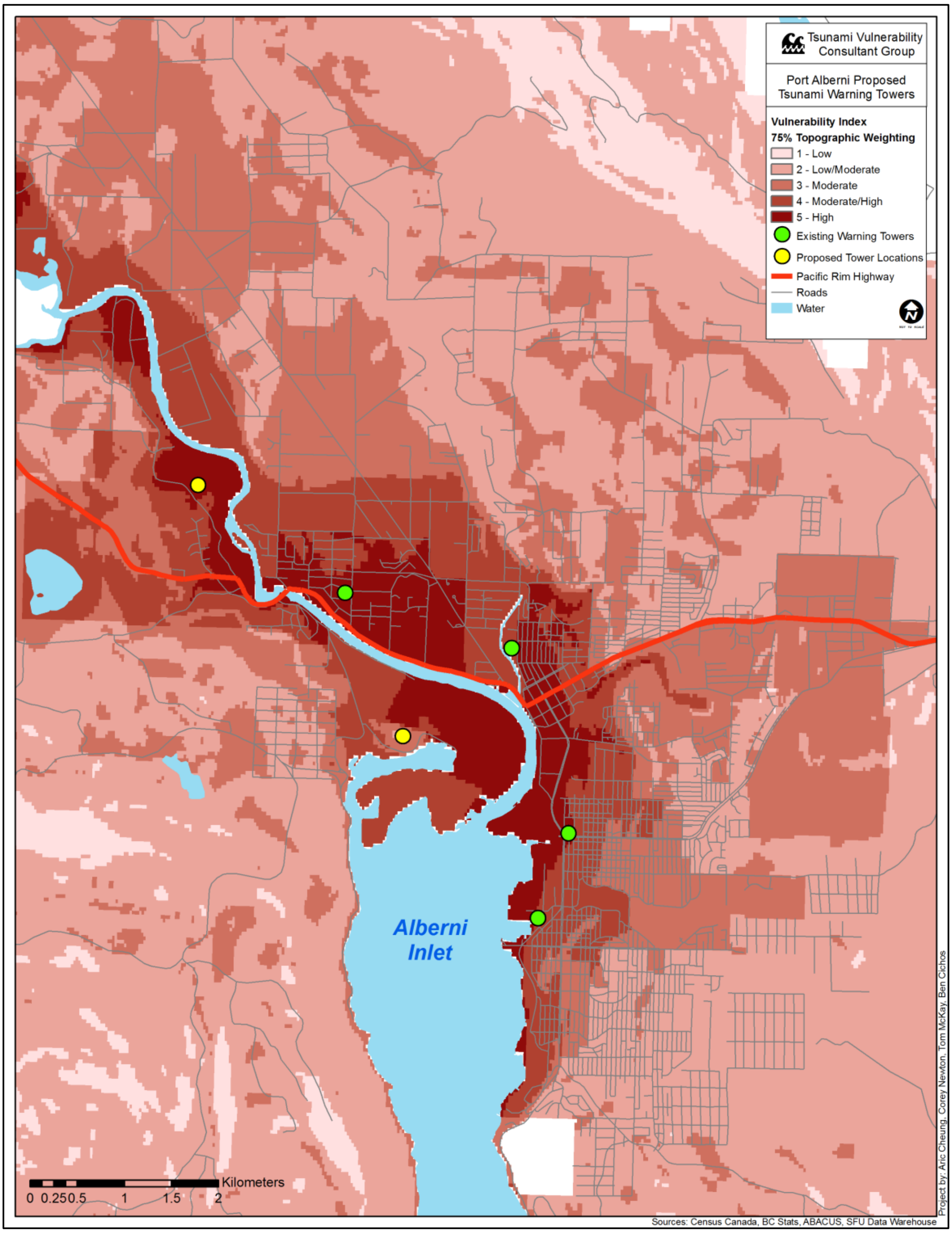

Figure 19: Siren Result

Discussion and Limitations

Some complications and limitations came with developing a vulnerability assessment for Port Alberni. First, the topographic data is mostly based off 30 meter DEM. The results could have been more accurate if a DEM with a higher resolution was found. Second, the data fusion process was decided upon based on a lack of better options. Rather than present a result with baseless assumptions, a range of results that can be interpreted by the client was chosen as a suitable solution. The drawback is that it does not present a definitive result, but rather many options from which to choose. Third, the safe points chosen for the Network Analysis were not assessed to see whether they could or would be willing to support a large number of people in the case of an emergency such as a tsunami. In addition, the bridges that were chosen to fail in one of the Network Analysis were not examined for structural strength and ability to withstand tsunami strength waves.

Demographic vulnerability could be further enhanced using block level data, but detailed data are not available for the block level. The decision to split the DA vulnerability index values into quintiles for representation may have an adverse effect on the data. However, since only a minority of residents are in very high risk areas, this bias seems apprpriate. The Indian Reservations can be assumed to be at a high level of social vulnerability but two reserves (in white) are outside of the overall tsunami hazard.

Conclusion

The goal of this project was to provide the city of Port Alberni with a local major tsunami vulnerability assessment that improves upon their past assessment while also presenting two possible new locations for tsunami warning sirens. This was gone about by using ESRI ArcMap software mainly, as well as Microsoft Excel, to analyse topographic data, as well as demographic data in order to create a holistic product that covers as many factors of vulnerability as possible while also maintaining strong support and rationale from literature review and logical solutions. It is due to this support, as well as our way of compiling risk for each dissemination area indiscriminately, that we feel our results are an improvement on past assessments, as well as a useful product for the city of Port Alberni. However, this assessment could be improved with the inclusion of wave modelling to give an even more accurate representation of which areas of town could be affected by a tsunami, as well as addressing the limitations that were previously discussed. Regardless, it is important for small communities such as Port Alberni to have some idea as to how their town could potentially be affected in the wake of such a disaster. With the information produced from this assessment, they could improve upon their emergency planning and as result, be more prepared for when the next major tsunami hits.

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Appendices

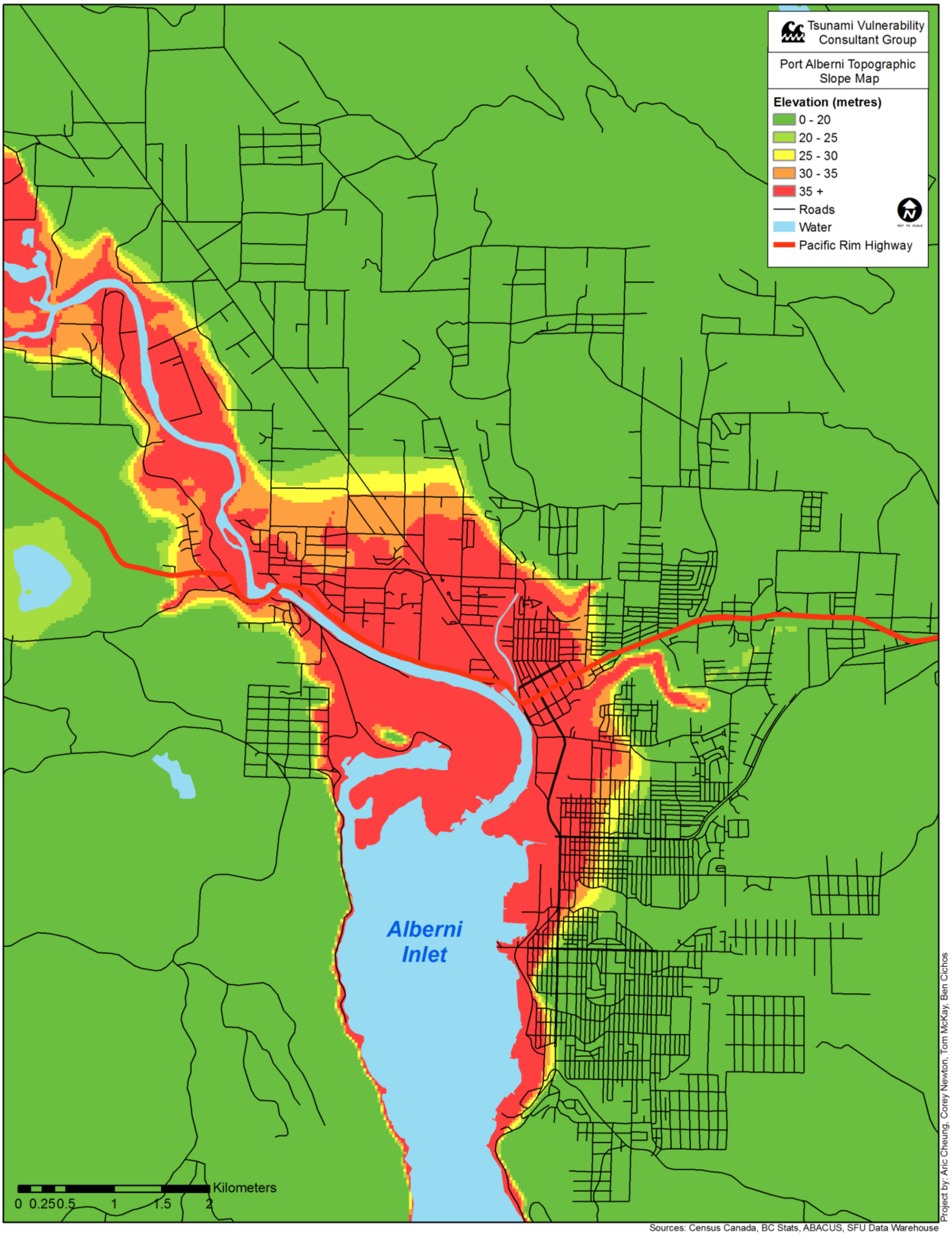

Figure 20: Elevation

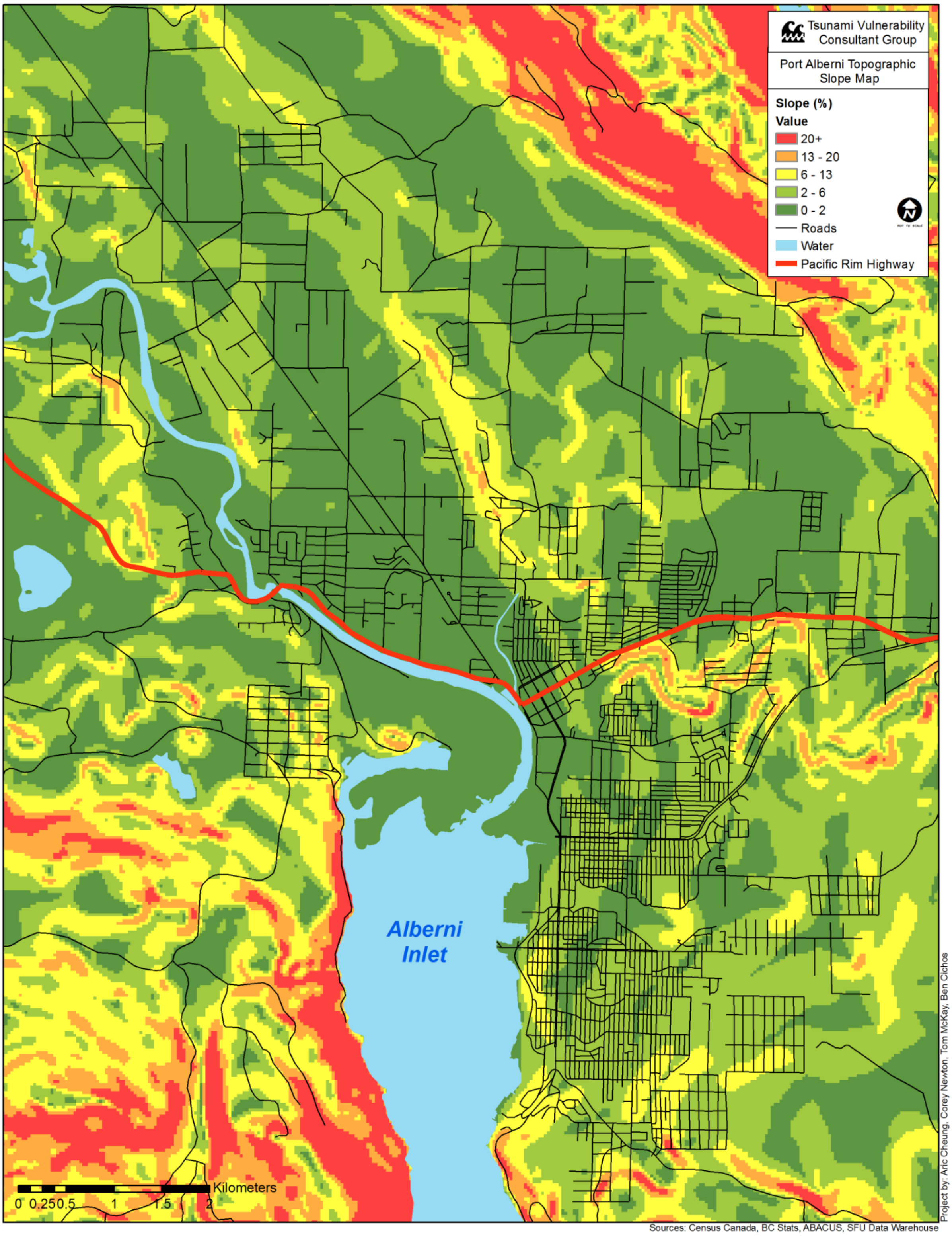

Figure 21: Slope

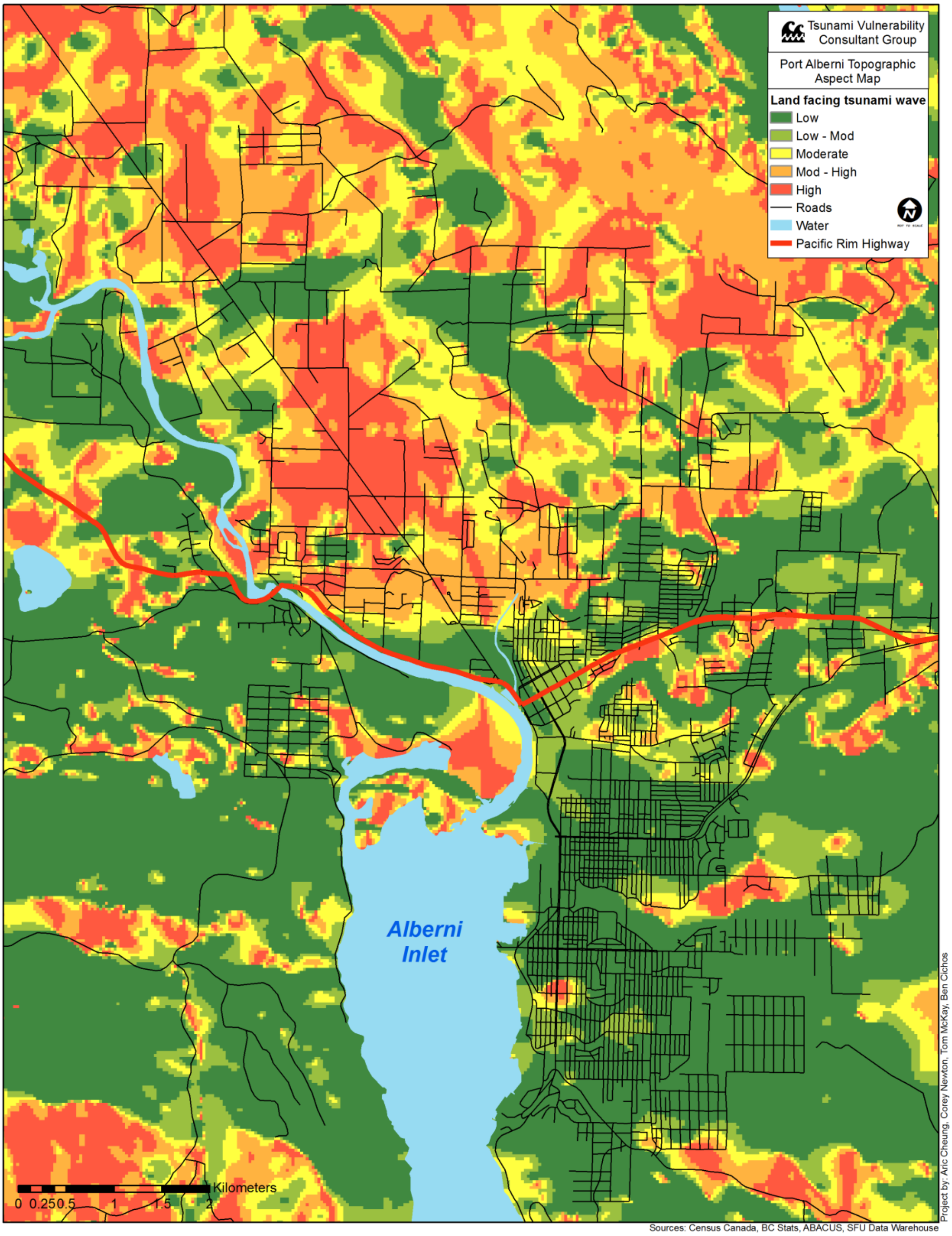

Figure 22: Aspect

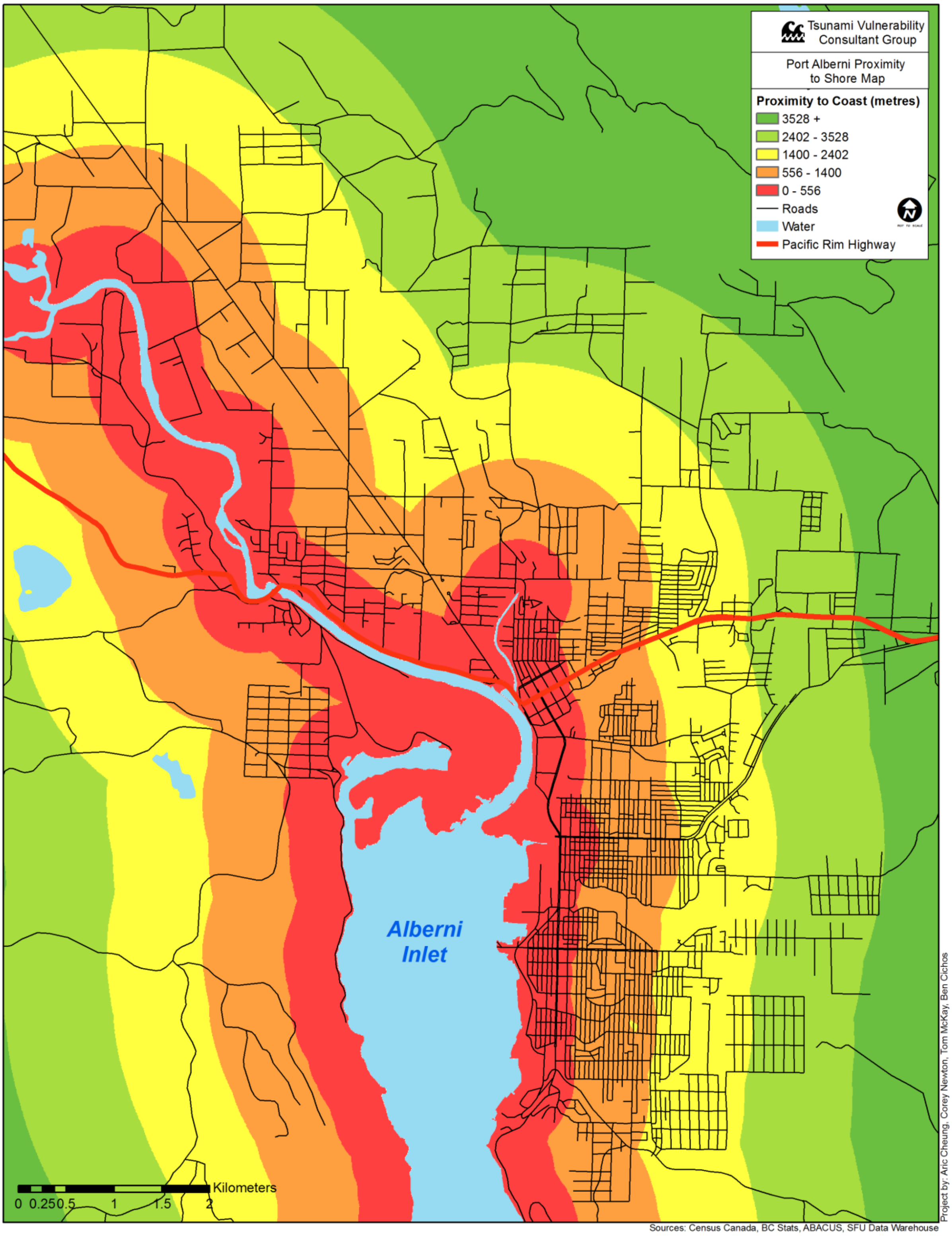

Figure 23: Proximity

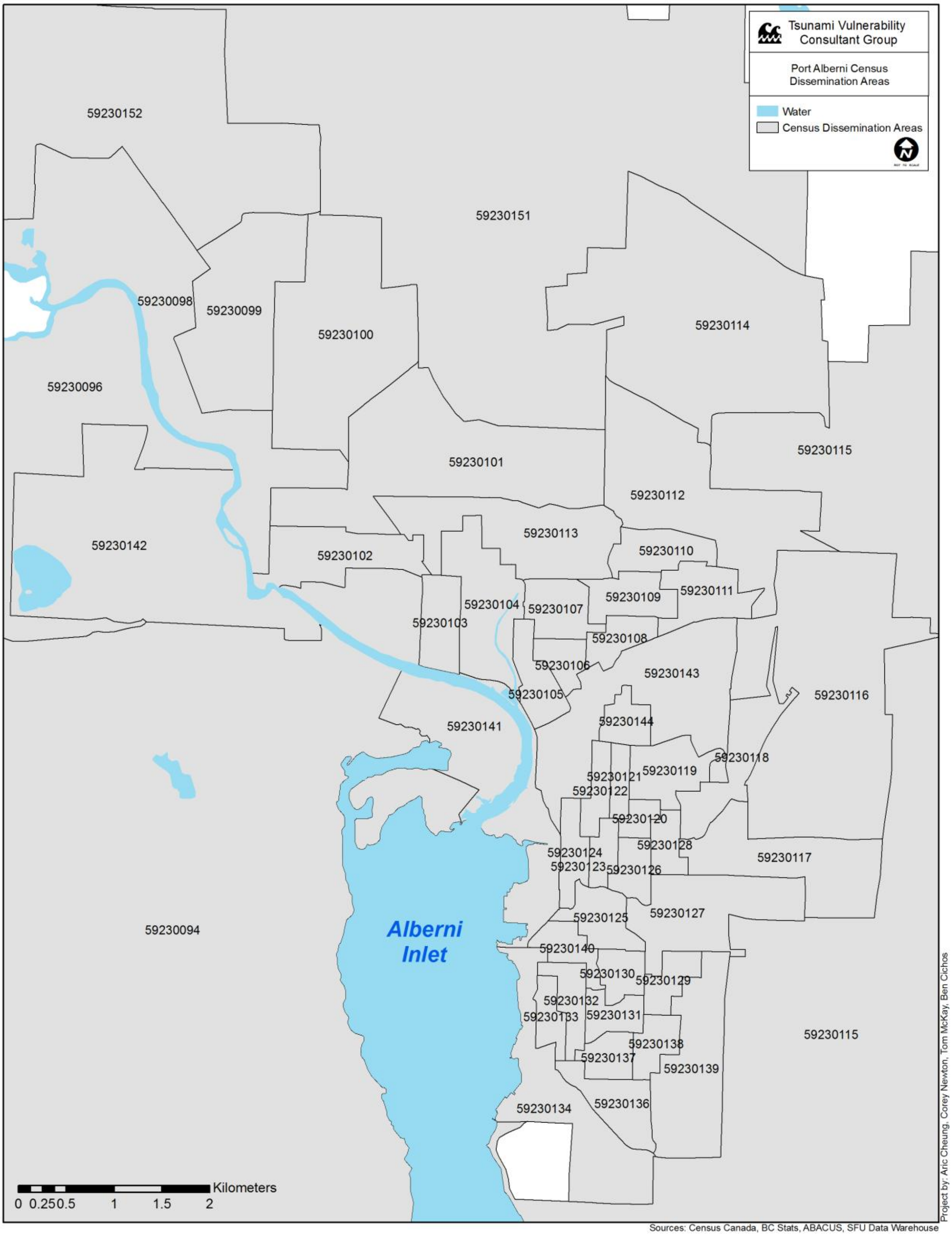

Figure 24: Census Dissemination Areas with IDs