Tsunami Vulnerability for Tofino and Victoria on Vancouver Island, BC

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Abstract
The two municipalities of Tofino and Victoria fall within the Canadian Pacific coast (CPC). The Canadian Pacific coast is a highly seismic region susceptible to intense flooding from potential tsunamis off the coast of BC. These two communities in particular are vulnerable to flooding due to their geographic location along the coastline. Through using GIS software, maps focused on the communities of Tofino and Victoria were created. Our results highlighted areas within these communities that were most susceptible to flooding. Factors that were taken into account when assessing an area's vulnerability to flooding included population density per square kilometer, total population, elevation, distance from shoreline, and geographic location of important infrastructure (hospitals, schools, and government offices). Results from Victoria showed that two schools would fall under the potential flood areas. In addition, results show that a significant number of people will be affected in Victoria based on population density and total population analysis. Results for Tofino showed that a sizable amount of people fall within the buffer zone, although the total amount of people affected would be less than Victoria, mainly due to a smaller overall population in Tofino.

Project Description
Located on the Pacific Ring of Fire, the Canadian Pacific coast is littered with many islands that are home to thousands of people within well established communities. The Pacific Ring of Fire is a chain of approximately 452 volcanoes that extend up to the Yukon, and is known to contain serious potential for volcanic activity (D. Conners 2016). It is an extremely dynamic and seismic region which could potentially trigger intense tsunamis. Two areas that are of particular interest for this project, Tofino and Victoria, are both waterfront communities located on Vancouver Island. We chose these two communities to focus our analysis on because Tofino is known to be one of the most sought after tourist destinations in Canada, and Victoria, as the capital of BC, is home to thousands of people and contains important infrastructure. Vancouver Island is particularly vulnerable to tsunami flooding due to its geographic location. Our research was interested in finding out how much flooding damage would potentially affect these communities. Vector data that was used in the creation of the maps included dissemination areas and municipal boundaries. These two data sets were important for giving visual information on boundaries. Raster data was used to create a Digital Elevation Model; this was crucial for analyzing areas susceptible to flooding based off of its elevation from the shoreline. Tabular data was also used to include total population data for both communities and was vital for determining the approximate amount of people that would be affected by flooding. A layer displaying geographic location of schools and hospital was created as another variable to consider as vulnerable to flooding. Through the creation of our maps we uncovered some interesting results that will be further explained in the Discussion and Results section of our project.

Methodology

Acquire:

To create the Basemap, municipal boundaries were taken from DataBC. These municipalities were further broken down into dissemination area (DAs) which were acquired from the UBC Data Library. Digital Elevation Model (DEMs) for both Tofino and Victoria were acquired the from local geography G: Drive. We obtained 2016 Census population density data for Tofino and Victoria from the CHASS Data Centre (University of Toronto). Data for schools, hospitals and government offices were acquired from DataBC. Data from DataBC were all projected as UTM Zone 10.

Parse/Filter:

Most of the data acquire from DataBC had to be filtered as layers extended beyond the municipality boundary. To look at data relating the Tofino and Victoria boundary, both vector and raster layers were clipped. These were the the DEM, shoreline, DA boundaries, population, schools, hospitals, government office - all clipped to the respective municipality layer. To display population (2016 census data from CHASS), tabular data of census information had to be joined to spatial layers. Joins are temporary so in order to save the join and make it permanent, the joined layers were exported to a new layer in order to not lose the selection. This was done for total population and population density for Tofino and Victoria. Some datasets from dataBC (hospitals, schools) did not have the regular download option, but a KML file format. Using the conversion toolbox, the KML file was converted to a layer, allowing us to view the points.

Mine:

Our analysis began with a reclassification of the DEM of both municipalities. In our reclassification, we selected 5 breaks manually based on the assumption that most of the tsunami risk would be capped at an 8m elevation. Our classes were 0m, 0-3m, 3-8m, 8-20m and 20m and above. By using these classes, we could rank the lower elevation classes as least risk, moderate risk, and high risk at up to 8m. We then converted the DEM into a polygon to further our analysis. Our resultant risk area was an intersection of the 1 km inland from shore buffer, which we felt was an appropriate distance from the coast, and the up to 8m in elevation parameters. This lead to the next step in our analysis, which was calculating the area of the risk polygon. This polygon is necessary to our analysis to determine the percentage of the total municipality in each case that was covered by the risk area. Our analysis was continued by building a multi field query using the select by attribute tool. The select by attribute tool helped us locate the original municipalities to set as the basemap for our analysis. It also was useful in query building to locate schools that intersected with the flood risk area, and to see their name and address in the attribute table. By selecting by attribute, we were able to calculate the sum of polygons easily and see where each dissemination area was in respect to the location on the map.

Represent:
Considerations for preparing the map included picking color schemes that would not easily confuse shades and therefore values on the legend. We settled on shades of green for the population density data, and blues for the total population map. For the elevation maps, we chose a neutral color scheme of shades from blue to yellow. For the population maps, we decided to put both Tofino and Victoria on the same map to make comparison easier. It is important to represent the population statistics on the same map so that users can look at both population scales and see the contrasted values alongside the maps to take into account the differing population density per square km. It was important to us that viewers of the maps would understand that Tofino has a significantly greater land mass with a significantly lower population/population density per square km than Victoria.

When preparing our maps, we ensured clarity and ease of reading to be the most important aspects. We had to consider a land mass confined in a dissemination area in Tofino that had a population of zero, and came to the conclusion that it was inhabitable for permanent residents, due to beaches and campgrounds in the area.

Table of Datasets:

Dataset Name	Attributes/ Tabular Data	Source
DEM	Raster/ value (elevation)	G: drive
DA boundaries	Vector/ Canada DA boundary files	Data Library UBC
Vanisland_population	Tabular/ population data	CHASS, U of T
Municipal_boundary	Vector/ municipal boundaries	DataBC
Vanisland_schools	Tabular/ schools	DataBC
Vanisland_hospitals	Tabular/ hospital	DataBC
Vanisland_govtoffices	Tabular/ govtoffice	DataBC
Vanisland_coast	Vector/ outline of coast	DataBC
Map_sheet	Vector/ map sheet	Open Data Canada

Discussion and Results

Elevation:

Two maps created to show elevation for Tofino and Victoria. The DEM was reclassified to highlight regions that fell under 8m in elevation as 'areas of risk'. Tofino's total elevation ranged from 0 - 86 meters which were broken down in 5 classes (manual breaks). The five classes that were a result of the classification were 0, 0-3m, 3-8m, 8-20m and 20-86m. The highest area of elevation is concentrated on the northern tip of the municipality. The area of high elevation is consequently where the main road/town center is located. Whether this area was planned as the main town center strategically to mitigate tsunami risk or consequentially is unknown. The largest tsunami risk is seen towards the south of Tofino. This is a problematic region, as the Pacific Rim Highway runs through this which serves as the only link from Tofino to the rest of the island. In a tsunami scenario, it could be possible that this link could potentially be rendered hazardous to use and can cause people on the island to get stranded. Elevation in Victoria's municipality ranges from 0 m to 127 m which are again broken in 5 classes (manual breaks). Areas that were deemed to be at risk were around 2,868,195.91 m^2. The total area of the combined DA's in the Victoria municipality was 19,511,834.38 m^2. Therefore, the risk area covered 14.7% of the total area. Most of these 'at risk' areas are regions along the coast line, with an area cutting through the city centre. The risk area for Tofino was calculated to be 2,298,124.99 m^2. The total area of the combined DA's for the Tofino municipality is 10,761,325.61 m^2. The risk area can be calculated as comprising 21.36% of the total area covered by the DAs.

Population Density and Total Population:

Victoria has a higher number of dissemination areas than Tofino. The dissemination areas in Victoria have a significantly higher population density, with the lowest bracket of population density in Victoria ranging higher than Tofino's largest bracket of population density. ranging from 823-3000 per square kilometer being larger than the biggest bracket of Tofino, which ranges from 174-326 per square kilometer. There are quite a few dissemination areas in Victoria of the highest population density that fall within the risk area. This is indicative of more people in an area being affected by the potential tsunami. Even if the majority of the risk area falls on areas that have low population density, there will be quite a few people potentially affected by this risk area due to the high density areas intersecting with the risk area. It is almost impossible to calculate total population affected, as the total population is dispersed within a dissemination area.

Victoria also has a higher total population than Tofino. This is important to understand why Victoria has more facilities, services and potential disaster evacuation routes than Tofino. However, Victoria being the capital of BC and more popular area to inhabit does not make it more important than Tofino. Although Tofino is more isolated with a smaller population, it does have a significant tourist population, and regardless, needs an updated plan to mitigate damage from potential tsunamis. The seasonal tourist population in Tofino is difficult to measure, and so calculating the potential amount of people affected in the risk zone is nearly impossible.

Facilities:

We selected hospitals, schools and government buildings to include in our analysis. We believe these to fall under a category of facilities that are particularly vulnerable a natural disaster, especially a tsunami. The facilities we selected are vulnerable in terms of importance, infrastructure, and human life capacity - specifically school aged children and persons seeking medical care. Ideally, none of these facilities would fall within the disaster area, but upon analysis, it has come to our attention that some facilities are at risk and should take a course of action to prepare for a worst case scenario.

I. Government Buildings:

While government offices might not fall under this category completely, we selected them to be a part of our analysis with the mindset that government buildings are of importance to each municipality. After a disaster, it could potentially be an inquiry from the general public if their infrastructure was damaged. An important landmark that DataBC did not include is the Legislative Assembly of British Columbia, this is the official building of the provincial government band an extremely important landmark which does fall into our 'risk area'.

II. Hospitals:

Hospitals play a key role during natural hazard events. It is critical for governments/municipalities to strategically place hospitals and emergency care units in relatively 'risk free' areas. Health facilities are in the frontlines during natural disasters (in our case tsunamis) in providing treatment to victims in the aftermath of a disaster. It is important to calculate the risks associated, as patients are already very vulnerable. Victoria has one major hospital in its municipal boundary - Royal Jubilee Hospital that can hold up to 500 beds (Islandhealth.ca, n.d.). Tofino General Hospital on the other hand is much smaller and has 10 acute emergency beds (Islandhealth.ca, n.d.). Neither Tofino nor Victoria have any medical facilities that fall into our deemed 'risk areas'. However, it is important to note that in this model tsunamis are seen as an independent event. Medical facilities can be severely compromised due to earthquake events before a secondary event like a tsunami strike. They could also be affected by secondary events to tsunamis themselves, such as landslides. It is imperative for medical centres to be both structurally sound and able to cope with large influxes of patients during a disaster.

III. Schools:

Out of the 20 schools listed in the municipality of Victoria, 2 schools fell within our designated risk area. These schools are James Bay Community and Selkirk Montessori School. Our recommendation for the locations within the risk areas is to develop or update current disaster response and evacuation strategies. As it is unlikely the schools will be moved to a safer location, the next best course of action is for the individual schools to identify routes to safety for the students and faculty in case of a disaster such as a tsunami. If the risk zone were to be increased to a higher elevation than 8m, 4 additional schools would potentially be included in the risk area. These additional schools should develop disaster mitigation plans as well, but it is not at the same level of importance for these additional schools than the original 2 schools already within the risk area. Preparing themselves for a worst case scenario that could potentially impact them as well is a better course of action than ignoring warnings under a presumed risk area, and being ill prepared when an unprecedented disaster hits.

There is only one school in Tofino, which is not located near the risk area. It is situated on the area of highest elevation. A risk strategy for this school, and facilities in the municipality, would be to focus on safe and timely evacuations from the area, as Tofino geographically sits on the western coast of Vancouver Island, and is therefore situated in a more hazardous location than Victoria, in relation to tsunami impact.

Error and Uncertainty

Much of the error we encountered stemmed from our interpretation and extrapolation of the data. We can assume that the data is spatially accurate to the best of our knowledge as data was extracted from the British Columbian government database - DataBC using the same projection system (UTM Zone 10). Digital Elevation Models (DEMs) also extracted from the B.C government are 25m coarse resolution - still accurate and precise but this could be increased with more finer resolution (e.g 1 m) from LiDAR data. The main uncertainty and error arises from our analysis of tsunami vulnerability and prediction, as this model is based on assumptions that only areas affected would be regions below 8 meters in elevation and 1 kilometer from the shoreline. This was an arbitrary choice as it is extremely hard to determine the impacts of tsunamis mainly due to the nature of them. Intensities of tsunamis depend on epicentre, depth and magnitude (if caused by earthquakes) resulting in more intense tsunamis if shallow and closer to the island and vice versa. Further research needs to be undertaken to create more accurate models on the effects of tsunamis. For example, maps could account for cascadia's 'big one' or smaller, more frequent ones. Since the model is based on arbitrary values (8 km elevation, 1 km inshore) these predictions might not be accurate predictions of what might actually happen in future earthquake/tsunami scenarios.

Resilience of selected structures were not accounted for in the analysis as it is difficult to quantify damage due to the lack of information on building/zoning codes on current structures. Error could thus stem from buildings deemed 'at risk' but in reality might be able to withstand tsunami effects due to improved infrastructure design. It is also important to note that these maps have been generated which sees tsunamis as an independent hazard to risk zones. The effects of earthquakes have not be accounted for. So the situation may arise where infrastructure could potentially be damaged by an earthquake event prior to the arrival of a tsunami.

Another key error/ uncertainty comes from our population data. Classification of our dissemination area (DAs) was colour coded based on population density. However, calculating populations affected by the flooding is grossly overestimated. To find DAs that fell into flood risk zones, the select by attribute function was used. However, since we did not have each individual represented, the whole DA was accounted for in populations affected by a potential tsunami. This error is particularly large for Tofino as each dissemination area has a small area that is deemed as a risk and hence the whole DA's population is considered to be at 'risk' while in reality that might not be the case.

Tofino's year round population is significantly lower than Victoria's. This is due to the fact that Tofino is a popular tourist destination and hence seasonality would affect total population in the municipality at any given time. It would be hard to quantify risk to human life as populations can fluctuate throughout the year.

Further Research

After our analysis we identified areas, that with further research, would benefit this tsunami risk report by reducing the error and uncertainty. We propose research centered on Vancouver Island, due to its vulnerable location. Namely for the risk zone: if 8m in elevation and 1 km inland from the shore is a sufficient zone to mark as the risk area. Due to the Island's geographic location, it would take the brunt force of a tsunami as compared to Vancouver. From this example, research on if the distance and elevation for the risk zone on the island would need to be increased to higher levels than the risk zone for Vancouver, and what those numbers would look like. Another area that would benefit from research would be the secondary effects of these tsunamis, such as landslides, in this region. Potential landslide areas were not included in our risk zone, and would therefore need to be identified on the island, with the risk zone subsequently modified to reflect the secondary hazard.

We came across a dataset of roads on Vancouver Island that were highlighted as disaster evacuation routes. These routes on the island were severely lacking to the point that it would have adversely affected our report by including them on our maps. The municipality of Victoria had one disaster evacuation route, and the municipality of Tofino had none. These routes did not seem to lead anywhere in particular, except out of main cities towards the eastern coast shore. Even with these disaster routes, research needs to be done to identify what the supposed method of evacuation from the island in a timely manner would look like in the case of an impending tsunami. Further research is critical to establish pedestrian routes to safety away from the island, not just to zones of higher elevation on the island.

Further research would best be directed towards developing different strategies for differing levels of disaster. In scenarios involving different risk intensity, mitigation and potential evacuation strategies would look different based on the predicted/expected level of quantifiable damage.

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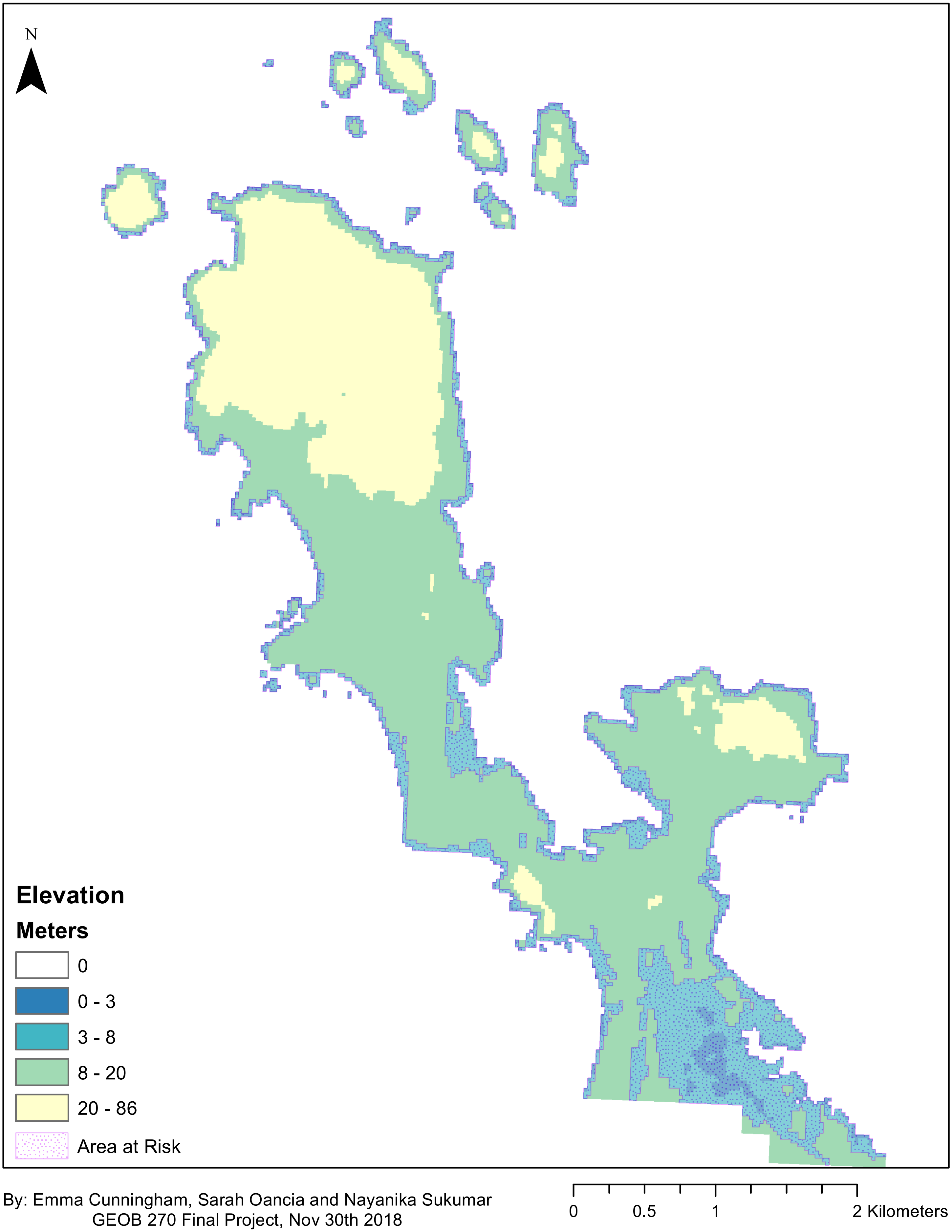
Islandhealth.ca. (n.d.). *Tofino General Hospital - Medical Imaging*. [online] Available at: https://www.islandhealth.ca/our-locations/medical-imaging-locations/tofino-general-hospital-medical-imaging [Accessed 30 Nov 2018]

Area at Risk of Flood in Tofino

Based on Elevation and Distance from Shoreline



By: Emma Cunningham, Sarah Oancia and Nayanika Sukumar
GEOB 270 Final Project, Nov 30th 2018
Affiliation: UBC Geography
Sources: DataBC, CHASS, UBC Library, UBC Geography
Projection: NAD 1983 UTM Zone 10

Area at Risk of Flood in Victoria

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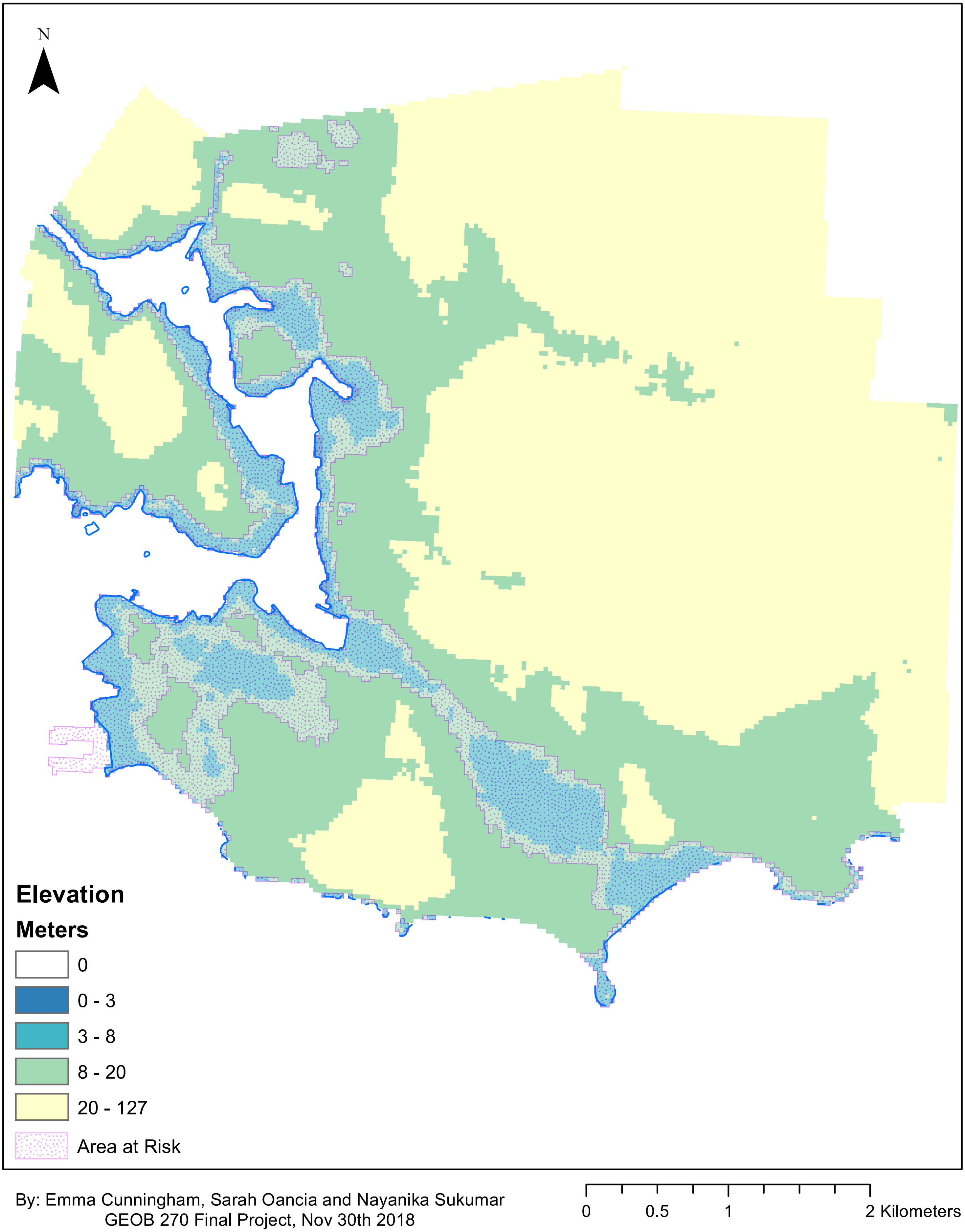

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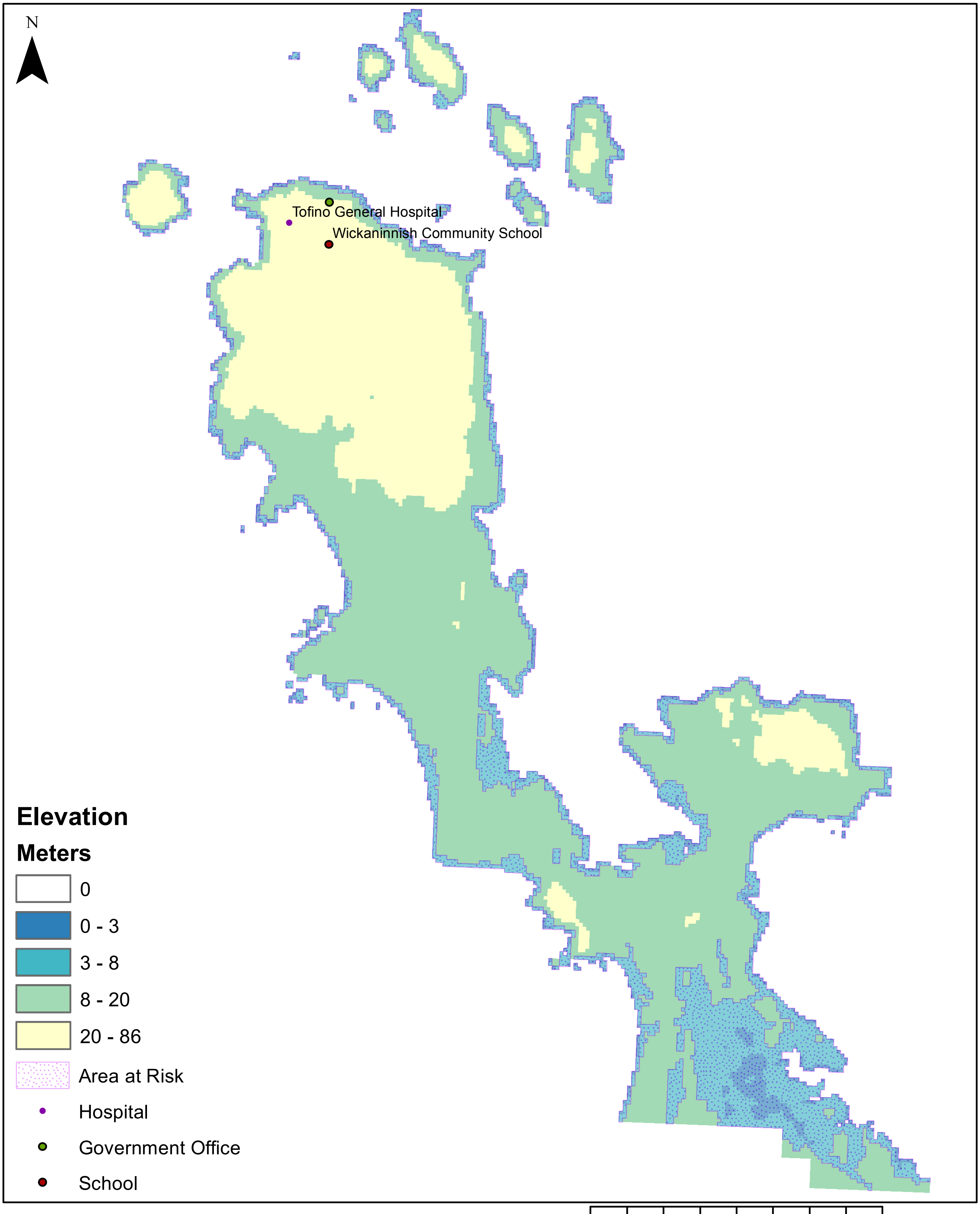
Schools, Hospitals, Government Offices at Risk of Flood in Tofino



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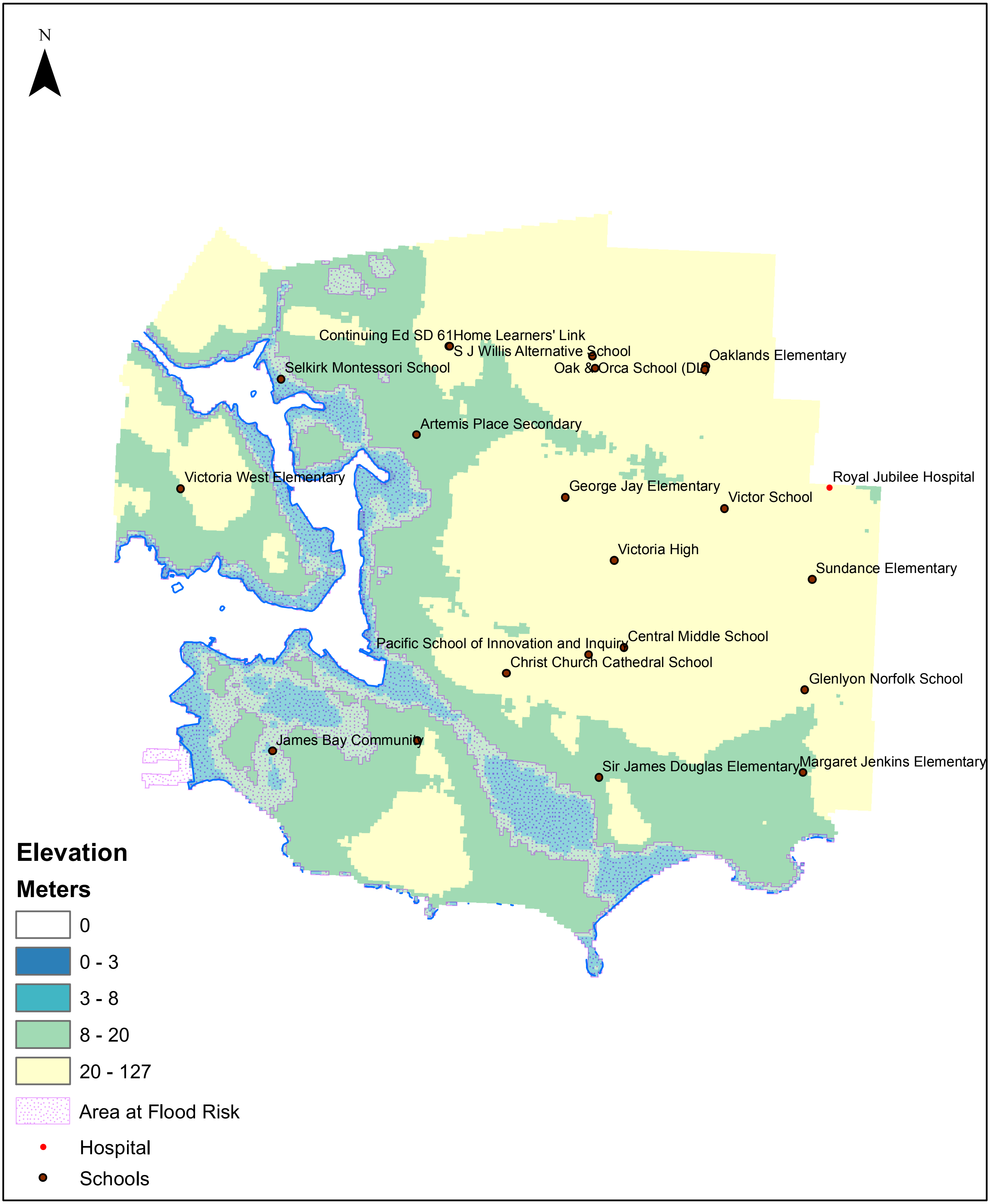

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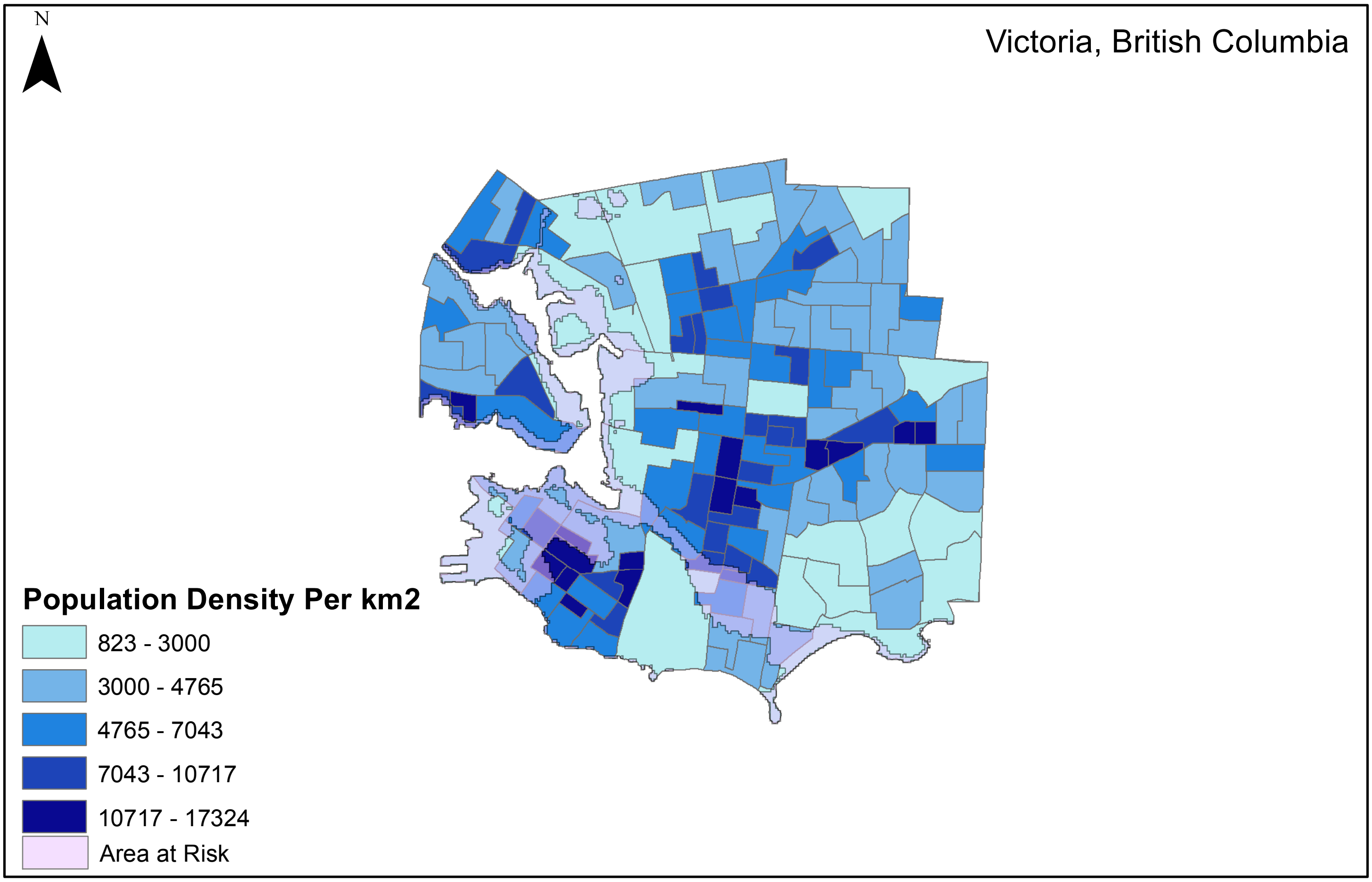
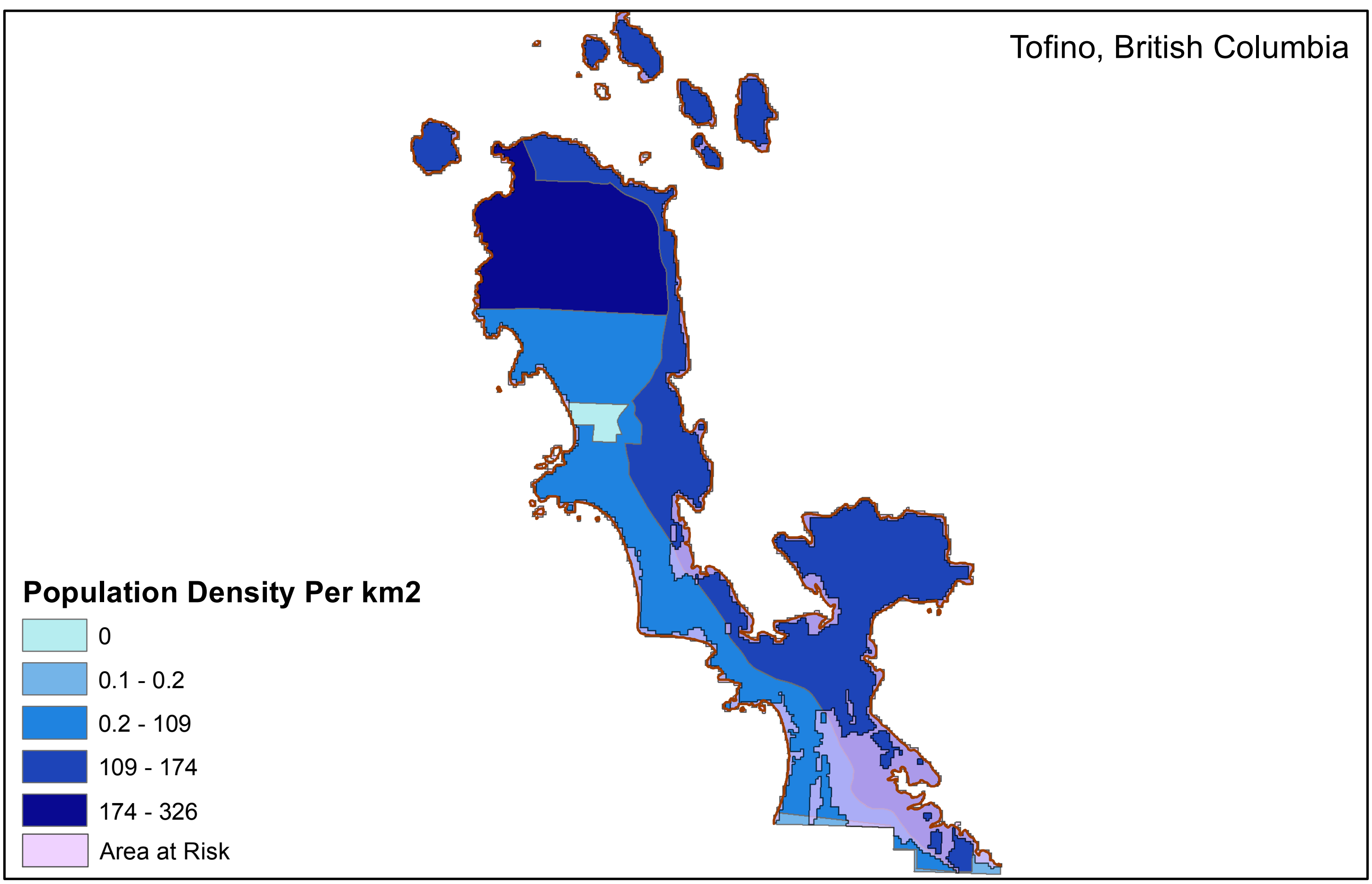
Areas at Risk From Potential Tsunami





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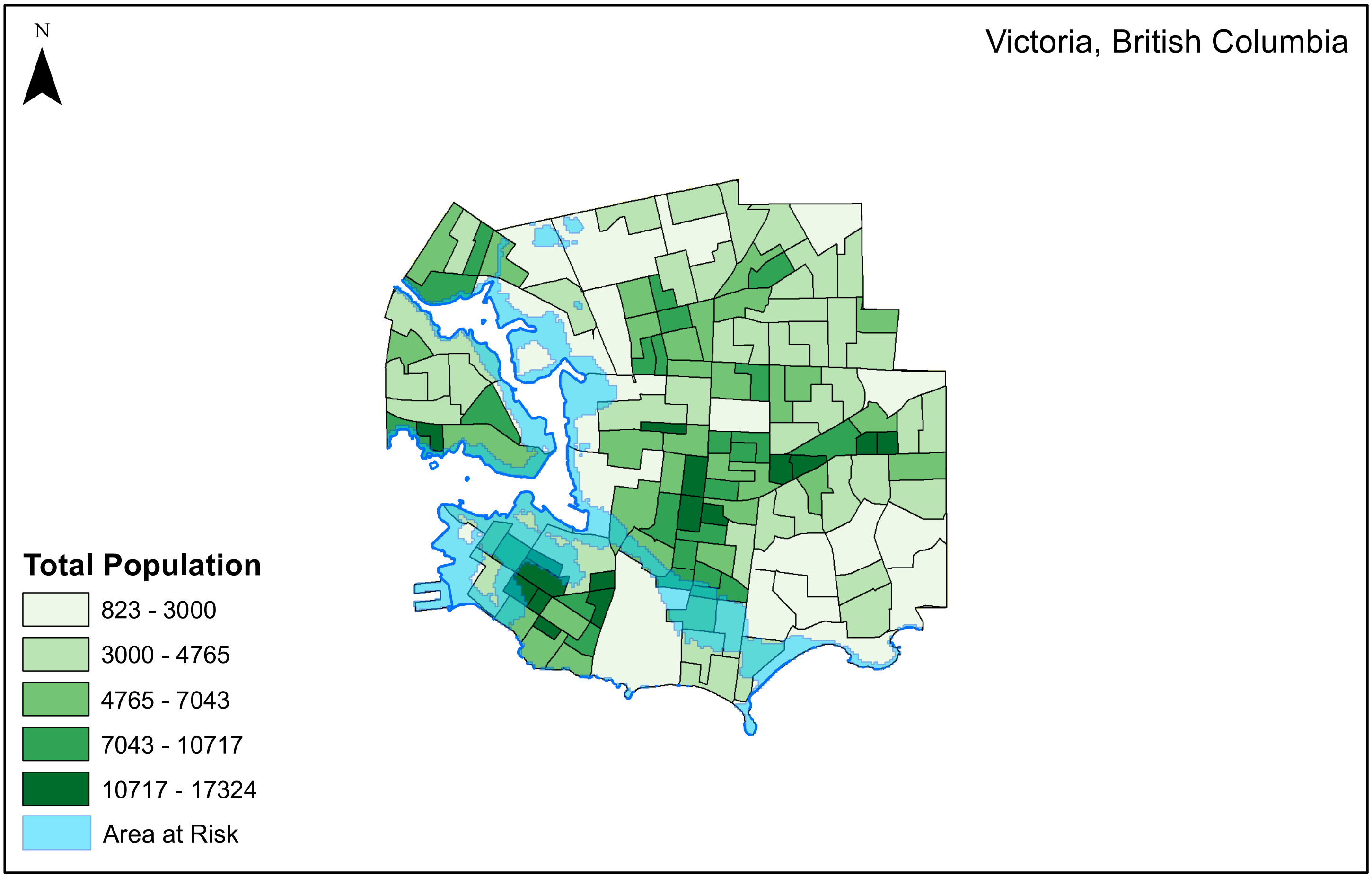
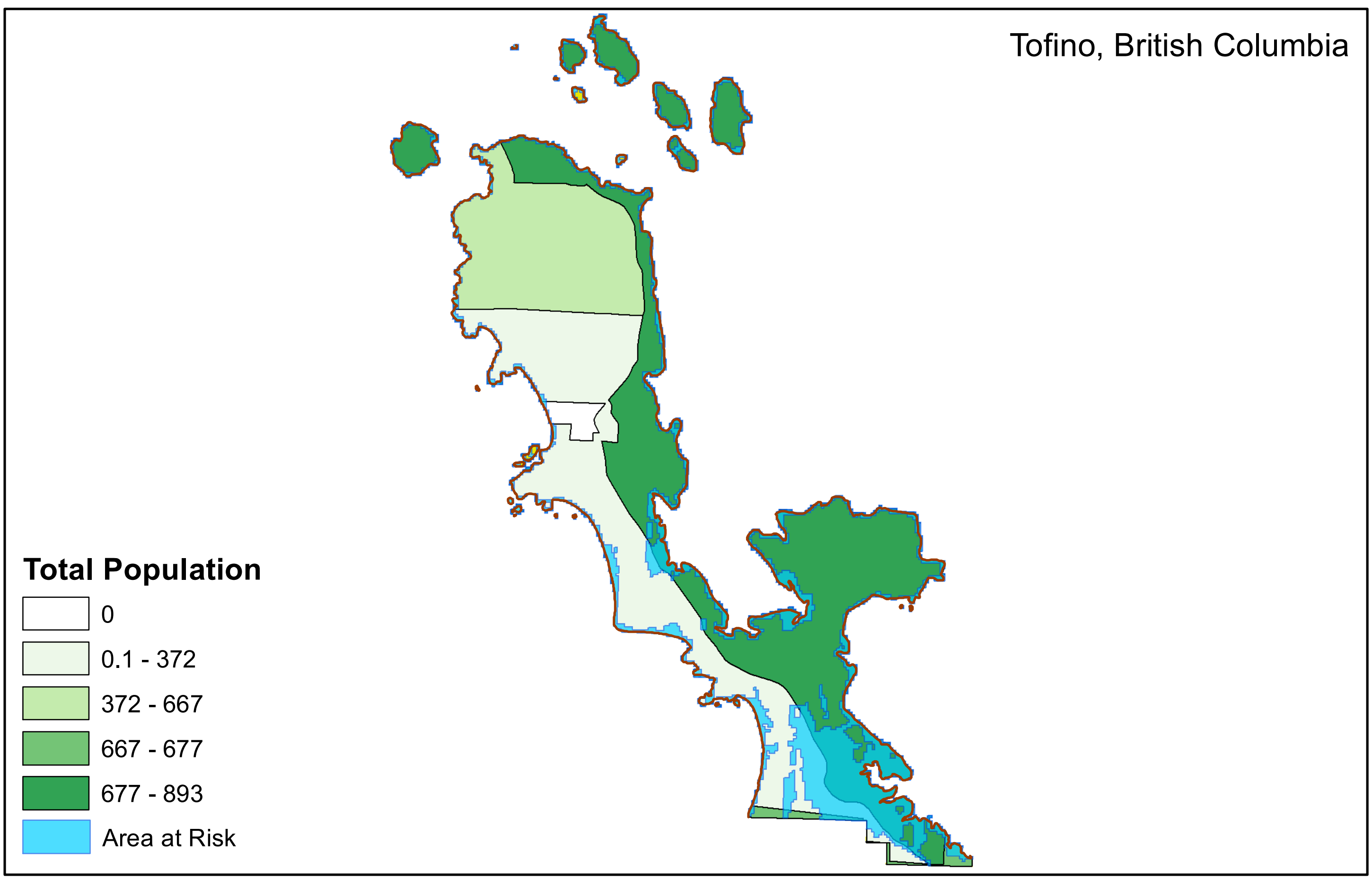
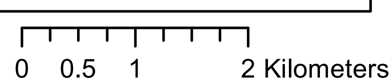
Areas at Risk From Potential Tsunami







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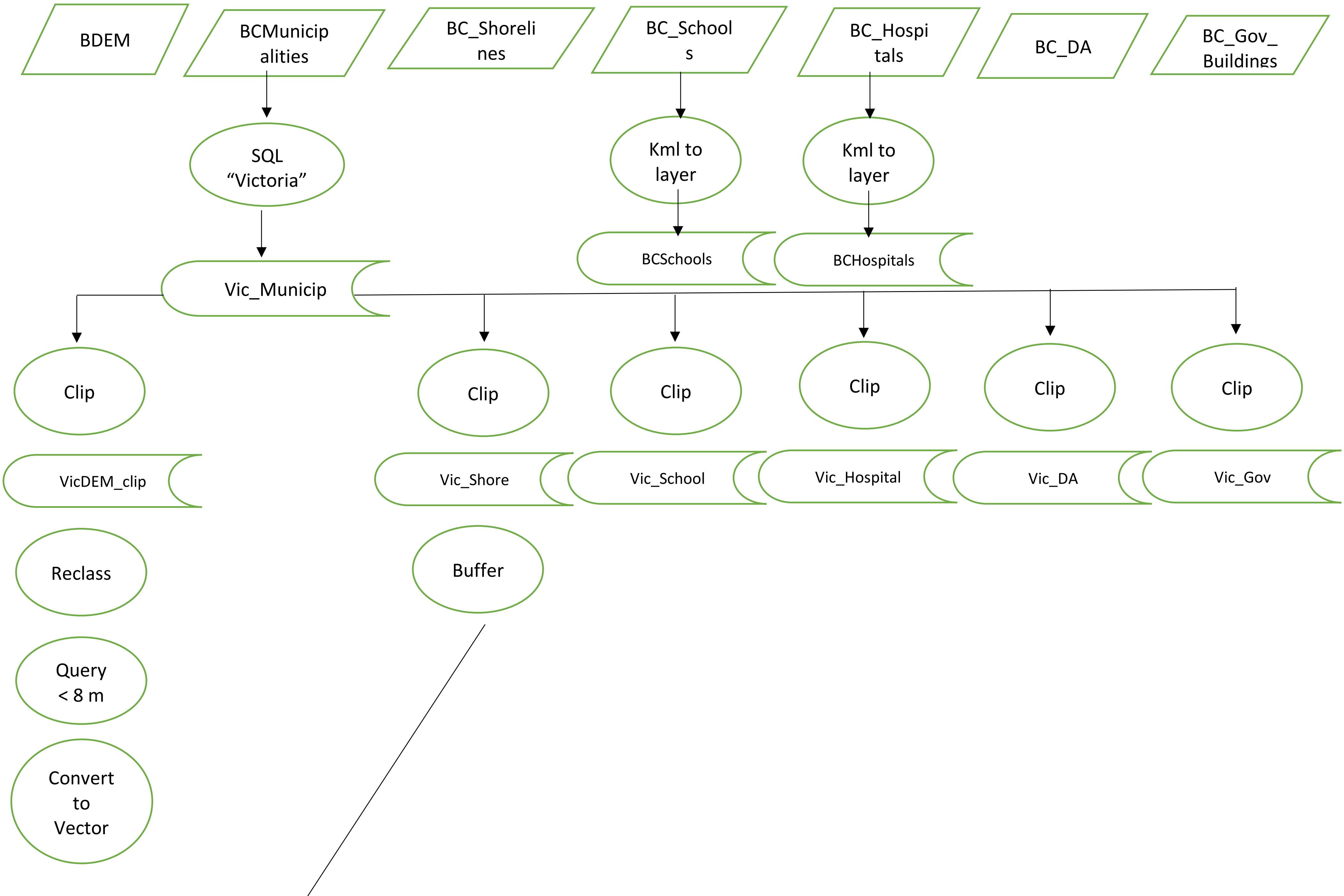

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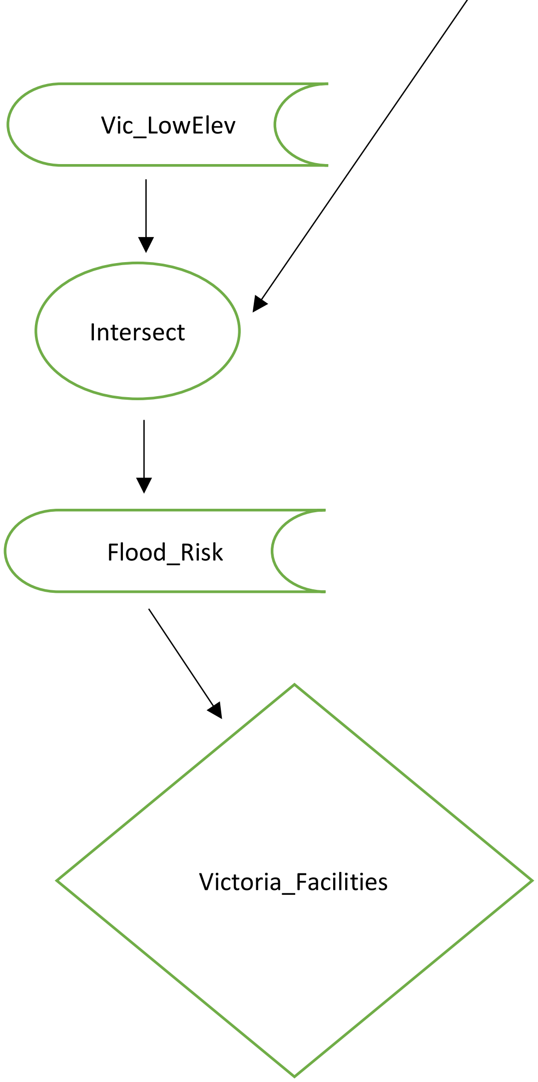
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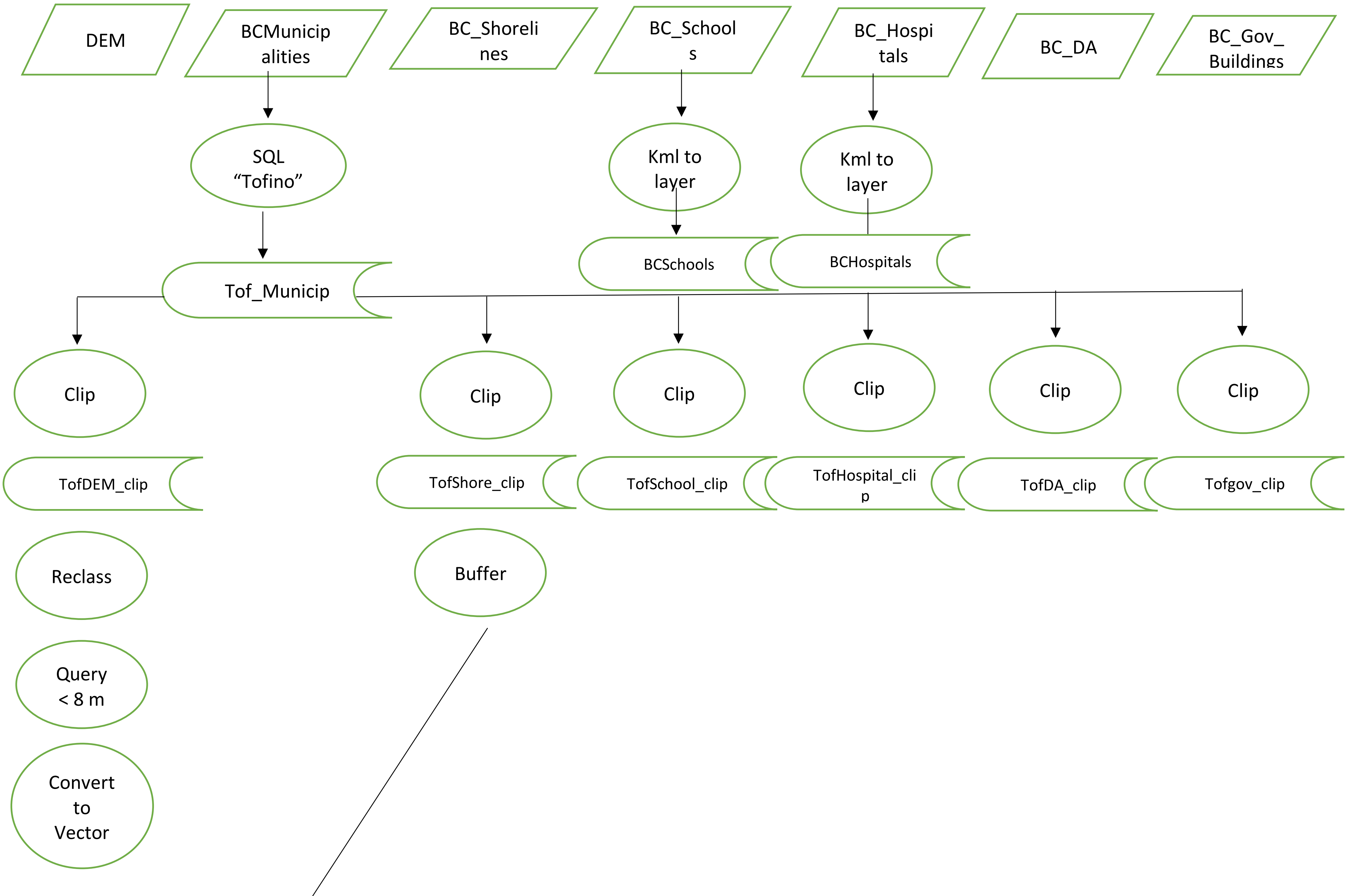
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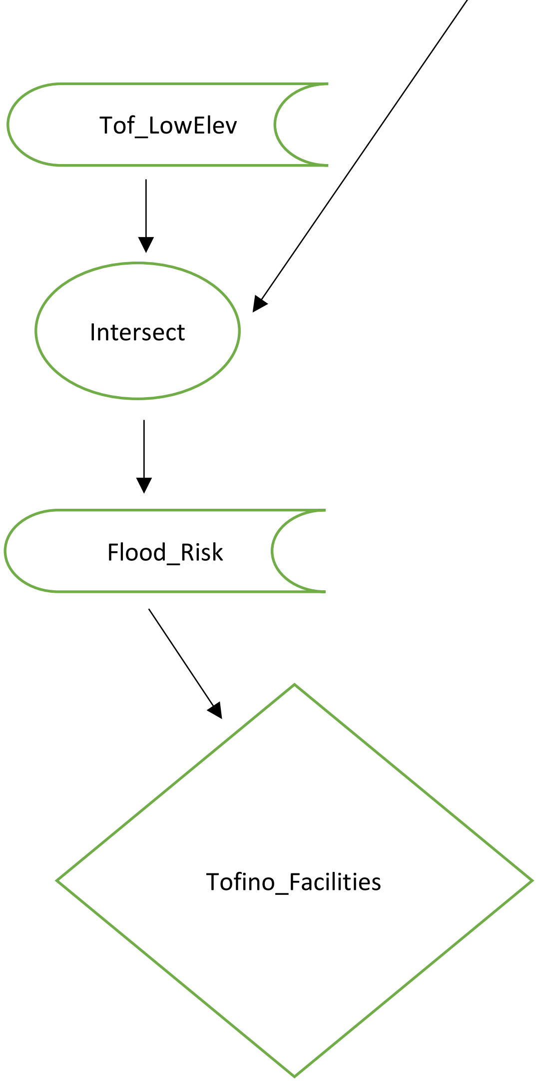
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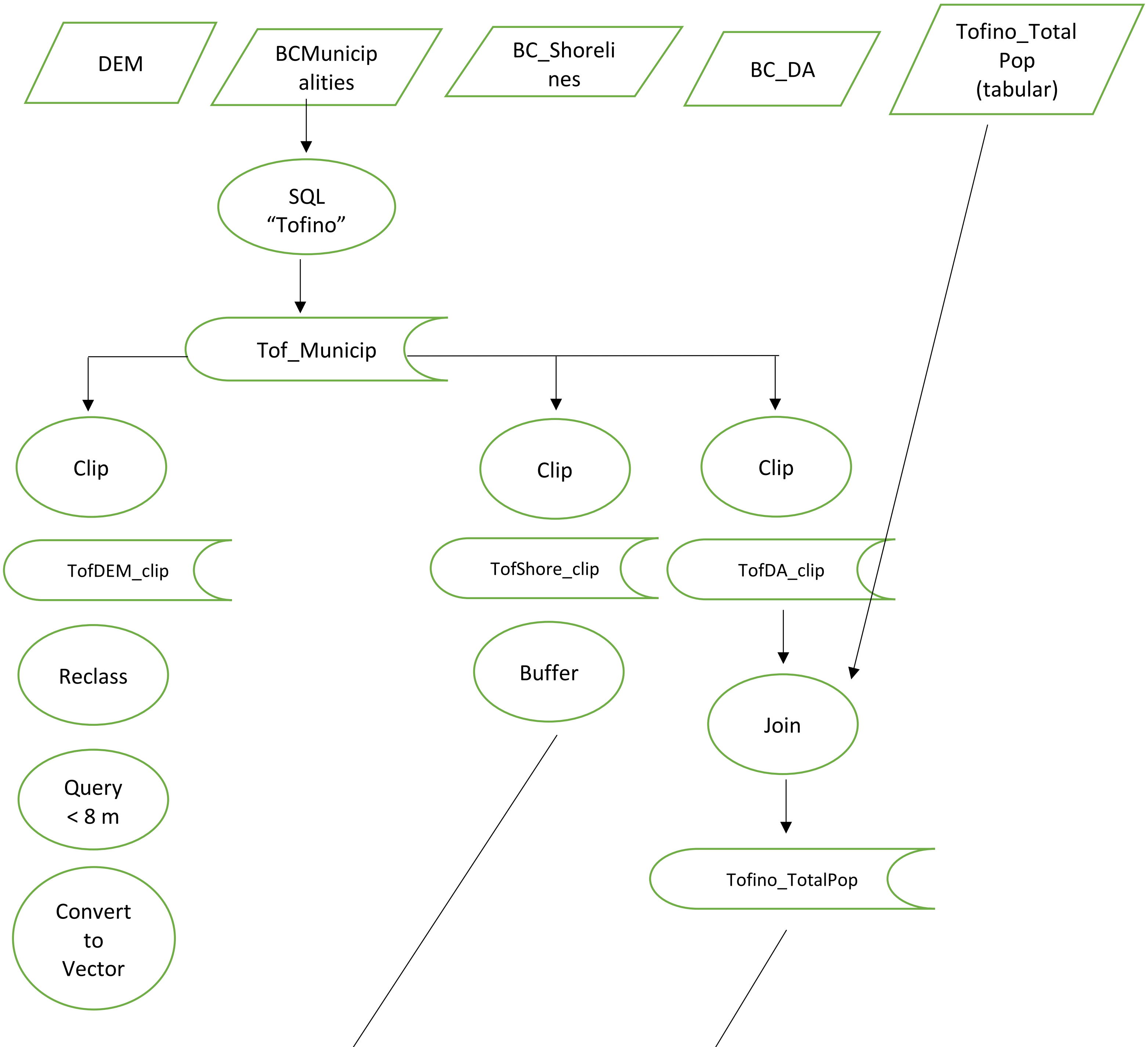

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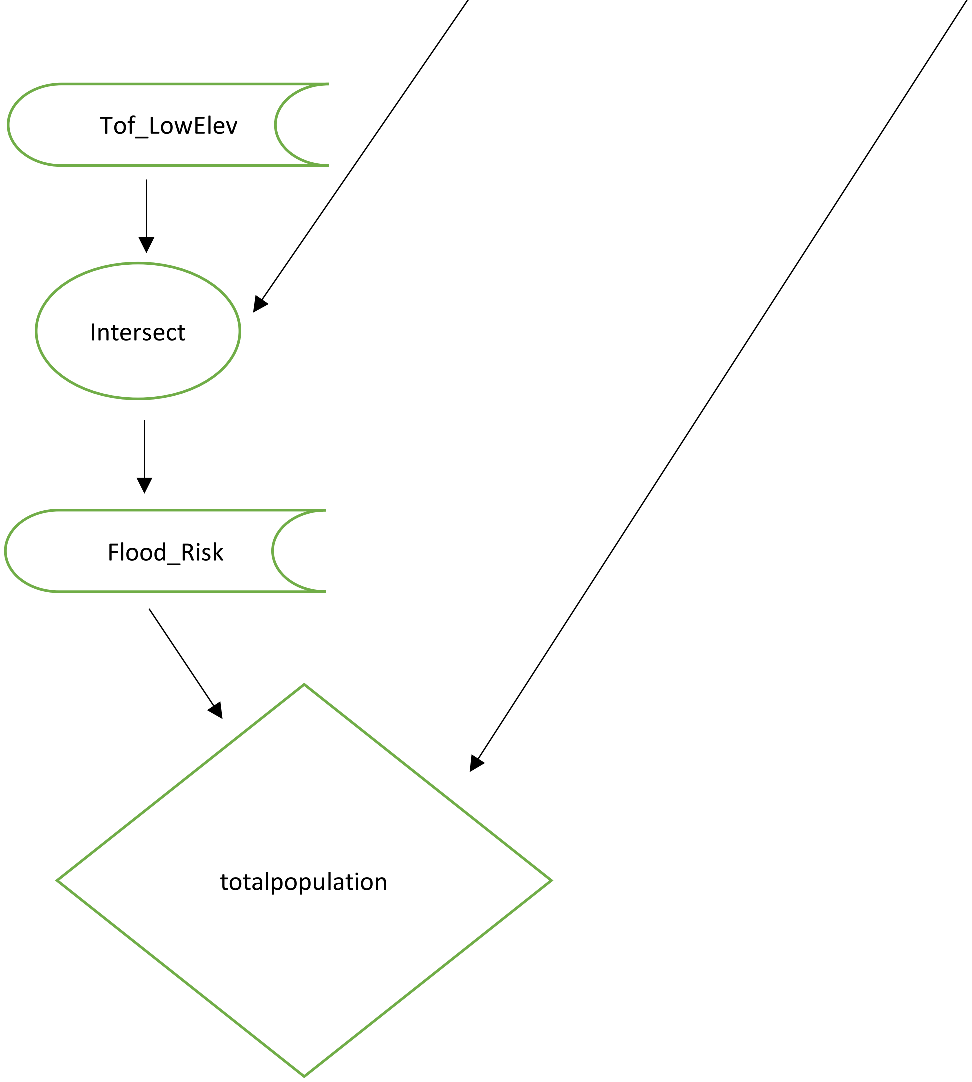

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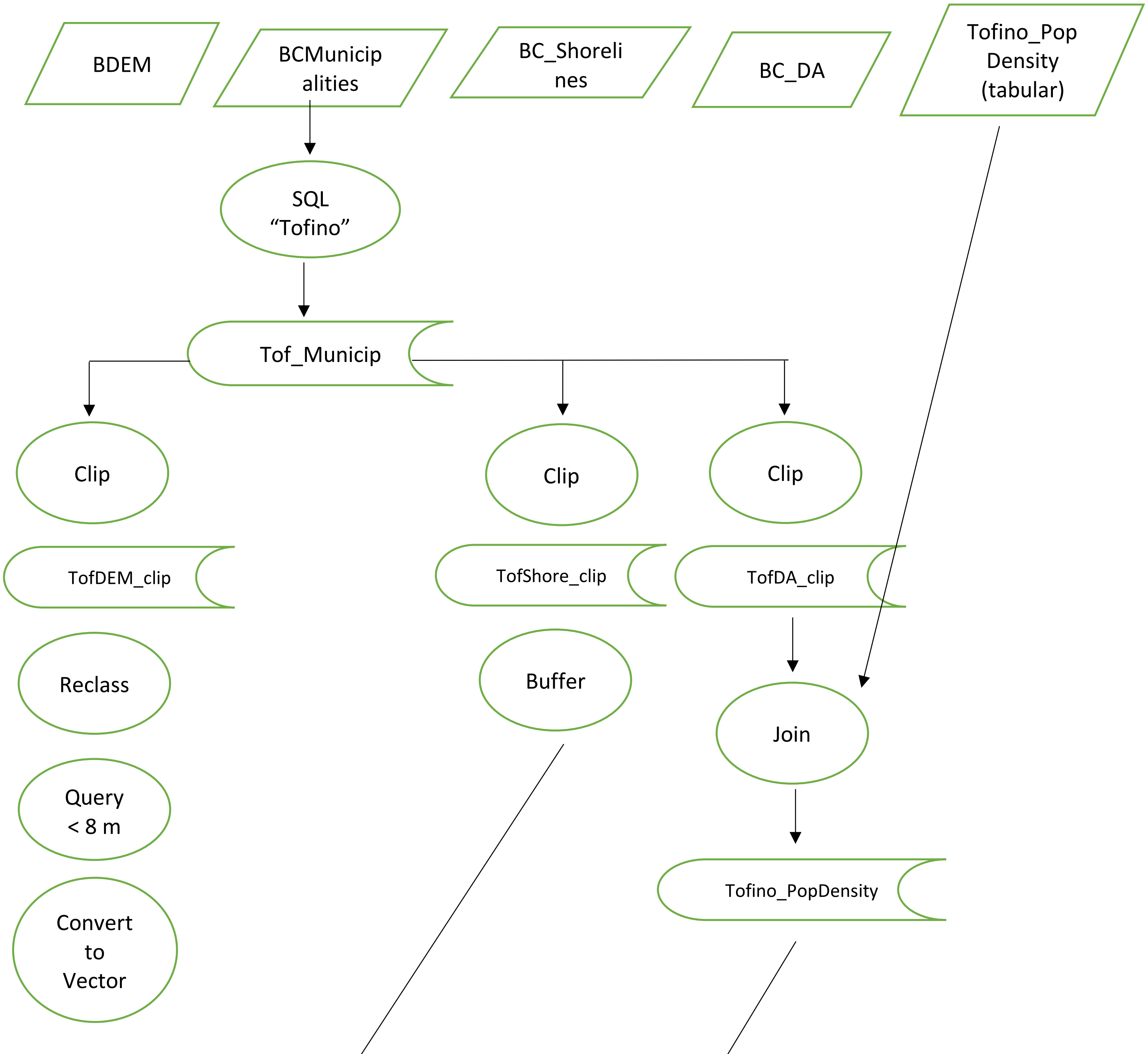
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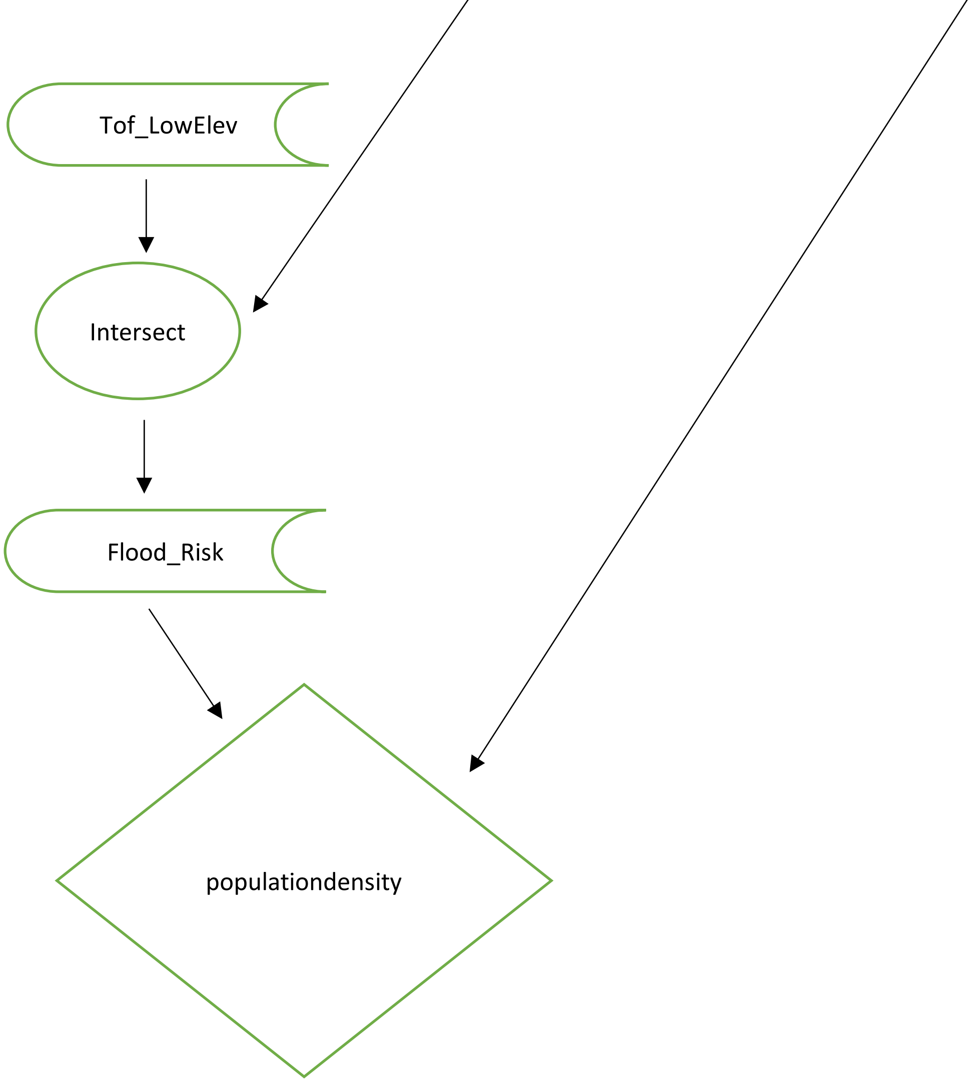
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