GEOB 270 GIS Final Project Report

Potential Risk and Exposure to Natural Hazards & Mitigation Planning in Richmond, BC

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• **Abstract**

Richmond, an island community in Metro Vancouver, is highly vulnerable to several natural hazards. River floods, high tides flooding, storm surges, earthquakes and liquefaction could create potential dangers towards the city. Perceiving that safety is an essential concern among Richmond residents, the awareness of potential hazards should be prioritized. The municipality government and residents are all playing a part to prepare for one's own safety. It is believed that "a little knowledge can go a long way to help minimize the damaging effects of any natural hazards."[1] Under those circumstances, risk assessments in natural hazards, preparedness and mitigation plans are the key segments in the City of Richmond administration policies.

This project aims to present the vulnerability of the City of Richmond in terms of its population density and private household values; the city's exposure to natural hazards, specifically flooding and earthquake; preparedness of the municipal government in terms of public safety services such as police/RCMP, fire-rescue, ambulance services and hospitals with major roads and highways will be mapped and analyzed.

• **Descrption**

City of Richmond is exposed to natural hazards such as flooding and earthquakes. Being aware of the potential risks of natural hazards and having a significant level of preparedness and mitigation planning is the key to minimize losses if such hazards take place. Having residents of Richmond stay informed about the hazards and enhancing mitigation planning is a highly important obligation by the municipal government to ensure the safety of human lives and economic properties. This project intends to assess and present Richmond's vulnerability and exposure level towards the above mentioned natural hazards as well as the level of the city's preparedness.

Map 1 focuses on presenting Richmond's vulnerability in terms of population and economic properties. Population density and private household values distributions in the dissemination areas (DA) of Richmond would be presented to determine which area in Richmond is the most vulnerable.

Map 2 shows a 5-metre flooding scenario to assess Richmond's exposure to this natural hazard. Richmond lies in the floodplain of the Fraser River delta, which is highly exposed to flood hazard. The map would first present the elevation of the city from the digital elevation model (DEM) and its dike system. The scenario of a 5-metre flood would be presented in illustrating how the hazard could impact the city.

Map 3 illustrates a 9.0 magnitude earthquake along the Cascadian subduction zone, where the epicentre is located based on some historical 5.0+ magnitude earthquakes' epicentre locations on the west of Vancouver Island. This scenario suggests how a high magnitude earthquake and its intensity may impact the City of Richmond. The land composition of Richmond would be presented to determine its vulnerability of liquefaction due to ground- shaking motions. Fault lines

[1] Earthquakes and Richmond. (n.d.). Retrieved from https://www.richmond.ca/safety/prepare/city/hazards/earthquakes.htm.

in the regions of Southern BC which might generate earthquake and impact Richmond would also be illustrated.

Map 4 shows the current mitigation plans and facilities within the City of Richmond. This map intends to assess the level of preparedness and mitigation planning by the government, by looking at the distribution of the public safety and health services within the city including police, fire-rescue, ambulance emergency services and hospital location. Major roads and highways as well as expressways are also provided on the map as evacuation routes, to assess the ability in evacuation when natural disasters take place.

• **Methodology:**

a. *Acquire*

The major source of data is from DataBC for its broader coverage and easier accessibility of public data provided by the BC government. The quality and reliability are high as the data is managed by professional authorities in BC Data Catalogue. Apart from DataBC, data is acquired from a number of sources like UBC Geography Drive, CanMap and CHASS for map-making.

b. *Parse & Filter*

Throughout the process of creating maps, different types of data files were downloaded, which were mostly .csv and .shp files. For tabular data files, such as .csv files, we mainly used 'join' to combine tabular data into layers' attribute table. For example, in order to demonstrate the population density of Richmond, we used 'join' to combine population density census data into the 'Richmond_basemap' layers. After doing this, we can demonstrate the population density by reclassifying the data.

For layer files, such as '.shp', we used 'clip' to create a new layer that is suitable for our basemap. For instance, our original 'river' layer contains all the river data in British Columbia. Therefore, in order to eliminate unrelated rivers, and to only show specific rivers surrounding Richmond, we clipped the 'river' layer onto the 'Richmond_basemap' layer to create 'Richmond River basemap'.

c. *Mine*

To conduct spatial data analysis for our maps, we performed 'query' (select by attribute), 'polygon overlay', and 'proximity analysis'. 'Select by attribute' refers to identifying useful and relevant features from a data set. For instance, in Map 1, we used 'select by attribute' function to get 'unique values' in creating the basemap of Richmond. Another example of select by attribute was carried out in Map 4, where we chose highways, expressways and major roads from the 'roads' dataset.

Furthermore, we utilized polygon overlays to integrate data from two or more sources to conduct spatial data analysis. In particular, clipping and displaying points were used in various parts of the map making processes. The function of 'clip' is to extend the overlay and to crop a region of focus. For example, as a result of using 'clip', we created the 'Richmond River basemap'. In all four of our maps, it was the basemap to visually present the information that we want to

highlight. Moreover, we used 'display XY data' function in ArcMap to display points of historical earthquake events of magnitude over 5.0.

d. *Represent*

Visualization considerations were made during the map-making process, like the colour and symbol choices to represent a feature on maps. For numerical data like population density or property values, the colour gradient was used to show the manual intervals. Specific spot locations were represented by dots or symbols on the map for easier interpretation. Basemap of Richmond was also added in facilitating understanding and establish linkages to map applications in reality.

In two of our maps, we used classification to highlight data of the maps. Therefore, for the population density and private households values, we used natural breaks to classify data into 5 classes. Whereas, for the map of flooding scenario in Richmond, we used manual break with only 2 classes for classification to distinct areas of flood and flood-free regions.

e. *Table of the dataset*:

Layer/datafile name	Source	Uses	Entity/data model	Attributes	Modifications
original: "dem92g" named: "DEM"	**Agency**: Open Data Canada **Date compiled**: Unknown **Data extracted**: elevation	determine the elevation levels of Richmond	raster DEM	value (elevation)	Clipping used to include the region for Richmond only
original: "shoreline" named: "shoreline"	**Agency**: Statistics Canada **Date compiled**: Unknown **Data extracted**: shoreline	determine the shoreline of Richmond	Vector polygon	N/A	Clipped the shorelines onto the boundaries of Richmond
Original: "lda_000b16a_e" Named: 'Richmond_Basemap"	**Agency**: UBC Data Services **Date compiled**: February 9, 2017 **Data extracted**:	Select Richmond areas from the datafile	raster	CTUID, CCSNAME, CDUID, DAUID	N/A

	Richmond area				
Original: "lhy_000c16a_e.zip" Named: "River"	**Agency**: UBC Data Services **Date compiled**: February 9, 2017 **Data extracted**: River	Showing river that close to Richmond	raster	N/A	Clipped the river onto the boundaries of Richmond
Original: "pIfzONnNrpL_data.dbf" Named: "population density"	**Agency**: Statistics Canada **Date compiled**: 2016 **Data extracted**: COL1(population density)	Determine the population density of Richmond in 2016	tabular	COL0, COL1	Join the COL0 and COL1 data into the 'Richmond_Basemap" layer
Original: "6EPNVvmimovE_data.dbf" Named: "Private household by tenure"	**Agency**: Statistics Canada **Date compiled**: 2016 **Data extracted**: COL1(private household by tenure)	Determine the household values after tax of Richmond in 2016	tabular	COL0 COL1	Join the COL0 and COL1 data into the "Richmond_Basemap" layer
Original: "PB2002_steps" Named: "Tectonic boundaries"	**Agency**: United States Naval Academy (US) **Date compiled**: October 6 2014 **Data extracted**: Tectonic boundaries on Earth	Show tectonic boundaries close to Vancouver	Vector polygon	N/A	N/A
Original: "FPW_FPWKLN_line" Named: "dykes'	**Agency**: Data BC **Date compiled**: March 9, 2011 **Data extracted**: Dykes of Richmond	Showing dykes that close to Richmond	Vector polygon	N/A	Clipped the dykes onto the boundaries of Richmond
	Agency:			N/A	

Original: "Road" Named: "Road"	CanMap **Date compiled**: Unknown **Data extracted**: Road of Richmond	Showing Richmond's highways, expressways and major roads	Vector polygon		Extract highways, expressways and major roads from "road" attribute table
Original: "(Original) Canada's earthquake.xlsx" Named: "(Final) BC's earthquake Mag _6.0.csv"	**Agency**: Government of Canada **Date compiled**: January 1, 2015 - December 31, 2018 **Data extracted**: Past earthquake over magituate 6	Showing the proximity of past earthquake events from Richmond	tabular	N/A	Extract past earthquake events over magnitude 6.0
Original: "BIO_ECODIST_SOIL_TEXTURE" Named: Sand layer & Clay layer	**Agency**: Government of Canada **Date compiled**: September 24, 2016 **Data extracted**: Sand and clay data	Showing Richmond land composition is made of sand and clay	Vector polygon	DESCRIPTION_EN	Clipped the layers onto Richmond boundaries

• **<u>Discussion and Results</u>**

Map 1: Vulnerability of Richmond towards Natural Hazards
[Population Density & Private Household Values]

Vulnerability is central to contemporary hazard research, also to the creation of practices and strategies to mitigate the impacts of disasters.[2] This map aims to specify the vulnerability of Richmond towards natural hazards, by taking a closer look at its population density and private household values.

[2] Bimal Kanti, P. (2011) Chapter 3: Vulnerability, Resilience, and Risk in Environmental Hazards and Disasters: Contexts, Perspectives and Management, First Edition. Oxford: John Wiley & Sons.

Natural breaks classification is used to population density and private household values of each DA. This characterization technique tries to limit the normal deviation from the class mean while boosting the deviation from the methods for different gatherings. The jenks recognize intelligent break focuses in an informational collection by gathering comparable qualities that limit contrasts between data values in a similar class and amplify the contrasts between classes. As classes are statistically different from each other, it is useful to reflect the underlying data distribution & outliers for population and property values in Richmond, BC.

From the map's interpretation, the highest population density with around 3000 people concentrates in City Centre. This means that the region is experiencing the highest vulnerability as more people are clustered, putting more at risk. There might be an increase in impacts to human lives. The private household values share similar situation which the highest values are also found in City Centre. Summing up, the government should put in more effort to enhance preparation such as stronger building structures to lower the disruption loss during any natural hazard. In advance, the City Centre area with the highest private household values and population will be clipped onto the flooding scenario map, in reflecting its exposure during flood events.

Map 2: Elevation Levels & Potential Flood Risks in Richmond [a 5m flooding scenario]

One of the natural hazards City of Richmond encountered in history and might encounter in the future is flooding. Richmond sits on the floodplain of the lower Fraser River delta with an average of only 1 metre above sea level. Historically, the lower Fraser River floodplain has been flooded 3 times severely in 1894, 1948 and 1972. It has the potential risk of future floods caused by sudden spring freshets from upper streams of Fraser River.[3] Possible high tides and storm surges could also cause flood hazards along the coastline.

A flood hazard analysis is created with 2 maps, with one showing the elevation of Richmond and the other showing a potential 5-metre flooding scenario. City Centre, the district zoning that has the highest population density and private household values shown in the previous map, is highlighted in red on this map.

The elevation map shows that the majority area of Richmond is below 5 metres above sea level. This flooding scenario shows that if a 5-metre flood takes place, a significant areas of Richmond would be submerged. Only a small portion of areas in central and east of Richmond would not be affected. City Centre with the highest population density and private household values, however, would be highly affected. This could cause severe outcomes of high casualties and property losses.

The dike network is the major flood protection facility in Richmond, which surrounds almost the entire city. It protects the city from river floods along the Fraser River and high tides and storm surges adjacent to the Strait of Georgia. However, the dikes have an elevation of roughly 4 metres[4], if a 5-metre flooding occurs, the dikes would be overtopped and unable to defend the majority of the Richmond areas from the floods. Also, there is a small area along the river bank in

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[3] City of Richmond. (2019, October 28). Drainage, Dike and Irrigation Operating and Maintenance. Retrieved from https://www.richmond.ca/services/rdws/dikes.htm.

[4] Wood, G. (2017, April 13). Richmond's $300 million dyke plan forges ahead. Retrieved from https://www.richmond-news.com/news/richmond-s-300-million-dyke-plan-forges-ahead-1.15299874.

southeast Richmond that has no coverage of the dikes. It could be highly exposed to the flood hazard and would be vulnerable without flood protection.'

Map 3: A 9.0-magnitude Earthquake Scenario & Land Composition in Richmond

Another natural hazard that places potential risk to the City of Richmond is earthquake. Ground-shaking motion of an earthquake could cause human casualties and infrastructure damage due to soil failure. Such motion could cause liquefaction on the water-saturated lands. Since Richmond sits on the floodplain of the Fraser River delta with low elevation, residents and properties within the region are highly exposed to the hazard.

The map is modelling a scenario of a 9.0 magnitude earthquake event, which takes place along the Cascadian subduction zone, west of Vancouver Island. Subduction zone occurs along convergent plate boundary, and generally, earthquakes associated with this plate boundary is extremely powerful. Thus, when the Juan de Fuca plate subducts under the North American plate, violent seismic activity will happen. Such earthquake scenario could place a great impact on the city.[5]

The modelling epicentre is estimately located based on the historical 5.0+ magnitude earthquake epicentres. "For years, experts have warned that the region is due for a major earthquake, potentially reaching a magnitude of 9.0",[6] therefore, a higher magnitude earthquake model is created to illustrate the worst case scenario. Despite the epicentre is several hundred kilometres away from Richmond, this earthquake could possibly cause impacts towards the city. The seismic waves are drawn with a 100-kilometre interval. The fault lines presented on the map show that Southern BC is an earthquake-prone area, with the fault lines covering the majority of Vancouver Island. Richmond, where it is "surrounded" by the fault lines, is highly exposed in the earthquake-prone region.

Land composition of Richmond is presented on this map. The entire land area of Richmond is covered by clay and sand. They have a relatively low bearing capacity which could only bear about 2000 to 3000 pounds per square foot, compared to bedrock composition which could bear 12,000 pounds per square foot.[7] Water-saturated clay would erode away easily with ground-shaking motion. When an earthquake takes place, ground-shaking motion would cause the loosely packed, water-saturated sediments to turn into a fluid mass. Liquefaction occurs and the sediments would lose their strength and can no longer fully support structures, which may lean or even collapse.[8] Such clay-and-sand land composition is highly vulnerable when an earthquake happens. Liquefaction might occur in the low-lying areas in Richmond, especially the lands with only 1 to 5 metres above sea level along the river banks and coastline.

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[5] City of Richmond. (2018, June 2). Earthquakes and Richmond. Retrieved from https://www.richmond.ca/safety/prepare/city/hazards/earthquakes.htm.

[6] Vomiero, J. (2019, July 6). B.C. earthquakes remind residents to look ahead to 'The Big One'. Retrieved from https://globalnews.ca/news/5464403/bc-earthquake-the-big-one/.

[7] Concrete Network. (n.d.). Why Soils Matter. Retrieved from https://www.concretenetwork.com/concrete/footing_fundamentals/why_soils_matter.htm.

[8] City of Richmond. (2018, June 2). Earthquakes and Richmond. Retrieved from https://www.richmond.ca/safety/prepare/city/hazards/earthquakes.htm.

Map 4: Disaster Preparedness - Public Safety Services, Major Roads & Highways in Richmond

Emergency responses and evacuation routes are essential for hazard preparation planning in Richmond. This map intends to provide clear guides and multiple references for people, in case a natural hazard strikes. For instance, public safety services like hospitals, ambulance stations, fire and police departments, as well as the major transportation routes are added onto the map. Vector structures and entities are used for network analyses and to represent discrete data for points and lines as attributes, also a vector polygon as the base map for Richmond.

From our implications, medical facilities in Richmond are quite insufficient. There is only one hospital in Richmond which its location is near the river with a very low elevation level. It is prone to inundation when flooding occurs. This is a crucial problem as the hospital services have already been limited in the region. If any destruction occurs in the structure when a hazard takes place, all medical treatments and assistance would be disrupted.

Besides, all ambulance stations are concentrated in the west of Richmond, meaning an uneven distribution of medical emergency response within the city. Despite the population of East Richmond is much lower than the west, the government should consider adding at least one station in the east. This could help shorten the medical emergency service distribution time to the east, possibly increases the efficiency of medical aid without further delays.

Similarly, accessing to the police stations is relatively hard for people in East Richmond as none of the police stations is located there. Most police stations are clustered in the west of Richmond, particularly near the centre of the city. Extra time might be needed for people in the east to get help. Accessibility of institutional safety services is vital to the public, therefore, adding one or two police station(s) in East Richmond is suggested to increase the efficiency of response and mitigation forces by the police department.

A total of eight fire stations are distributed in Richmond. The majority of the stations concentrates in the central area, only a very limited amount of fire stations are located in both the east and west of Richmond. Therefore, the fire-rescue services would be ineffective as firefighters might have to spend extra time travelling to the accidental spots in both city edges when a hazard takes place.

Lastly, the location of the major roads, highways and expressways are identified during the map-making process. The two highways which connect central Richmond to Vancouver are highly essential in evacuation, since those are the shortest routes that connect the highest population density area of Richmond to the neighbouring cities. Expressways link from the centre to the east and south of Richmond, providing another two major evacuation routes to the neighbouring cities such as New Westminster, North and South Delta. Exclusive coverage of major roads are also presented on the map as alternative routes, which could help increase evacuation effectiveness.

• **<u>Error and Uncertainly</u>**

Tabular-Vector Data Conversion

The first type of data uncertainty we encountered was the conversion from a set of tabular data to an ArcMap vector layer. The data set was firstly achieved from the City of Richmond BC website, which is a set of relevant data without geospatial references (x,y coordinates). We first tried to convert the data into an Excel or '.csv' file, then imported the data into the Richmond DA basemap in ArcMap. However, since it has no geospatial references, the above mentioned step was unable to process automatically. We resolved this problem by manually input the data into the respect vectors of the Richmond DA basemap.

DEM rasters

For the elevation levels of Richmond, a raster DEM is used. The pixel cells of 'dem92g' are quite large (25bits), the resolution would be relatively low, so the data might be less accurate for showing scales and areas, also less accurate for geodatabase analysis. Another problem for raster DEM is that the file size is much larger than a vector layer, so there are always delays in processing time. It also requires higher storage size with the larger file size. Thus, there will be tradeoffs between spatial accuracy, file size, display and processing time when using a raster DEM geospatial data.

Manual Data Entry Error of Tabular Data

For some data such as the Richmond Police Department, there were no tabular data available, such that we had to manually enter the information like x-y coordinates and names. As we did the data entry by hand, there will be a higher probability than computers to have errors. To minimize the errors, we performed a 'double-data entry' with two people entering the same data and checked it thoroughly to ensure the accuracy and quality of tabular data.

"Boundary Delineation" & "Highway Linkage" Problem for Vectors

For the basemap of Richmond, we have encountered difficulties when making decisions to draw boundaries between different zonings in Richmond. Subjective choices were made to define boundaries with discrete vector lines, and this might not be applicable in reality as the real conditions were modified to satisfy a better map visualization. There are false and strange boundaries observed from the 'East and West Cambie', 'Fraser Lands' and 'East Richmond' areas.

Also, on Map 4, highway that connects central Richmond to Vancouver through the Oak Street bridge is unable to show its connection on the river layer. When we clipped the"roads" layer onto the Richmond base map, the Oak Street bridge disappeared because it didn't count as an infrastructure for Richmond but Vancouver instead. This would create an error of presentation on the map, with the highway being disconnected on the river.

Inaccessible & Irrelevant Data

For this project analysis, geospatial data is very essential and important in making the maps. However, finding appropriate geospatial data for each specific map was challenging, especially some data set has licensing that require payment for access.

Some data achieved from open data sources could be irrelevant and contain logical errors. For example, when we were looking for a set of data about geological land composition in Richmond, we achieved a data set named "Soil Name and Layer Files", which ended up realizing it was a data set that related to Richmond soil type for agricultural land use instead of showing difference geological landforms. This data set was irrelevant to our map analysis and scenario.

• Further Research and Recommendations

Identifying public services in neighbourhoods that could possibly support Richmond

In case a natural hazard takes place in Richmond, resources and support from its neighbouring areas like City of Vancouver or City of Delta could be very helpful. By looking at geospatial data, it is possible to examine the proximity of nearby neighbourhoods' 'aids' to Richmond. Network analysis can be applied to optimize the shortest path and the most effective way to get help from other cities. A 'location-allocation' model through GIS could be used to identify the supply & demand systems by identifying areas that are less being reached in Richmond. Priorities should be setting up aids to the under-reached regions as well as positioning facilities to meet demand points in Richmond effectively. For example, resources that locate along Marine Drive in Vancouver would be the most efficient in distributing to East Richmond when a natural hazard takes place, as it is one of the major roads in Vancouver which has the closest proximity to Richmond.

Enhancing the Coastal & River Flood Protection Scheme

City of Richmond's 49-kilometre dike network is the major flood protection facility protecting communities from possible high tides, storm surges and river floods. Alongside the dike system, pump stations and water courses are the only flood prevention measures in Richmond as of 2019[9]. Such measures might be insufficient to prevent possible higher intensity floods. Therefore, additional enhancement of the coastal & river protection scheme should be considered, which more coastal protection facilities should be built. Other than upgrading the dikes, the municipal government could also include planting coastal forests and building extensive breakwaters along the coastline. Lastly, public emergency facilities such as evacuation centres should be planned ahead and distributed evenly within the area of Richmond, to increase public safety preparedness.

[9] City of Richmond. (2019, October 28). Drainage, Dike and Irrigation Operating and Maintenance. Retrieved from https://www.richmond.ca/services/rdws/dikes.htm.

• **Appendices**

i. Bibliography

Bimal Kanti, P. (2011) Chapter 3: Vulnerability, Resilience, and Risk in Environmental Hazards and Disasters: Contexts, Perspectives and Management, First Edition. Oxford: John Wiley & Sons.

City of Richmond. (2018, June 2). Earthquakes and Richmond. Retrieved from https://www.richmond.ca/safety/prepare/city/hazards/earthquakes.htm.

City of Richmond. (2019, October 28). Drainage, Dike and Irrigation Operating and Maintenance. Retrieved from https://www.richmond.ca/services/rdws/dikes.htm.

Concrete Network. (n.d.). Why Soils Matter. Retrieved from https://www.concretenetwork.com/concrete/footing_fundamentals/why_soils_matter.htm.

DMTI Spatial™. Road. Retrieved from https://www.dmtispatial.com/canmap/

Earthquakes and Richmond. (n.d.). Retrieved from https://www.richmond.ca/safety/prepare/city/hazards/earthquakes.htm.

GeoBC Inquiries. (2012). Digital Elevation Model for British Columbia - CDED - 1:250,000. Retrieved from https://catalogue.data.gov.bc.ca/dataset/digital-elevation-model-for-british-columbia-cded-1-250-000

Government of Canada. (2018). Earthquake Database. Retrieved from http://earthquakescanada.nrcan.gc.ca/stndon/NEDB-BNDS/bulletin-en.php

Government of Canada. (2013). Soil Texture by Ecodistrict. Retrieved from https://open.canada.ca/data/en/dataset/0b88062f-ebbe-46c6-ab19-54fd226e9aa7

Government of Canada. (2015). Canadian Digital Elevation Model, 1945-2011. Retrieved from https://open.canada.ca/data/en/dataset/7f245e4d-76c2-4caa-951a-45d1d2051333

GitHub. (2014). Tectonics plate. Retrieved from https://github.com/fraxen/tectonicplates

Jones, L.(2011). Geology Faults. Retrieved from https://catalogue.data.gov.bc.ca/dataset/geology-faults

Hahn, M. (2011). Flood Protection Works - Structural Works. Retrieved from https://catalogue.data.gov.bc.ca/dataset/flood-protection-works-structural-works

Fraser M. (2011). BC Health Care Facilities (Hospital). Retrieved from https://catalogue.data.gov.bc.ca/dataset/bc-health-care-facilities-hospital

Policing and Security Branch. (2013). Policing Jurisdictions and Regions in BC. Retrieved from https://catalogue.data.gov.bc.ca/dataset/policing-jurisdictions-and-regions-in-bc

Statistics Canada. (2016). 2016 Census Profiles Files [Population density]. Retrieved from http://datacentre.chass.utoronto.ca/grid3/2016/main/download_status.cgi?jobid=pIfzONnNrpL

Statistics Canada. (2016). 2016 Census Profiles Files [Private Household]. Retrieved from http://datacentre.chass.utoronto.ca/grid3/2016/main/download_status.cgi?jobid=6EPNVvmimovE

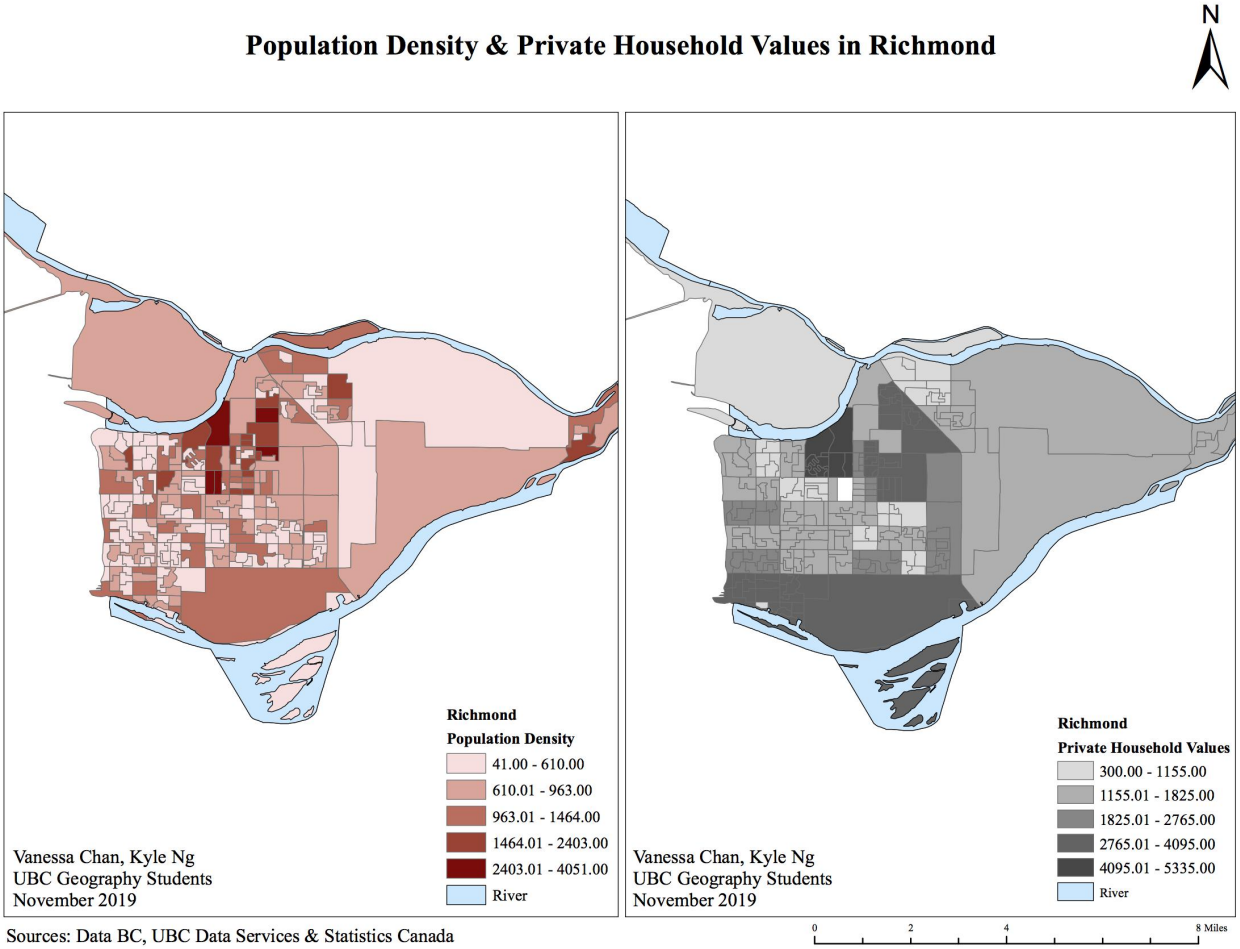
Vomiero, J. (2019, July 6). B.C. earthquakes remind residents to look ahead to 'The Big One'. Retrieved from https://globalnews.ca/news/5464403/bc-earthquake-the-big-one/.

Wood, G. (2017, April 13). Richmond's $300 million dyke plan forges ahead. Retrieved from https://www.richmond-news.com/news/richmond-s-300-million-dyke-plan-forges-ahead1.15299874.

Statistics Canada. Shoreline. Retrieved from https://www150.statcan.gc.ca/n1/en/type/data

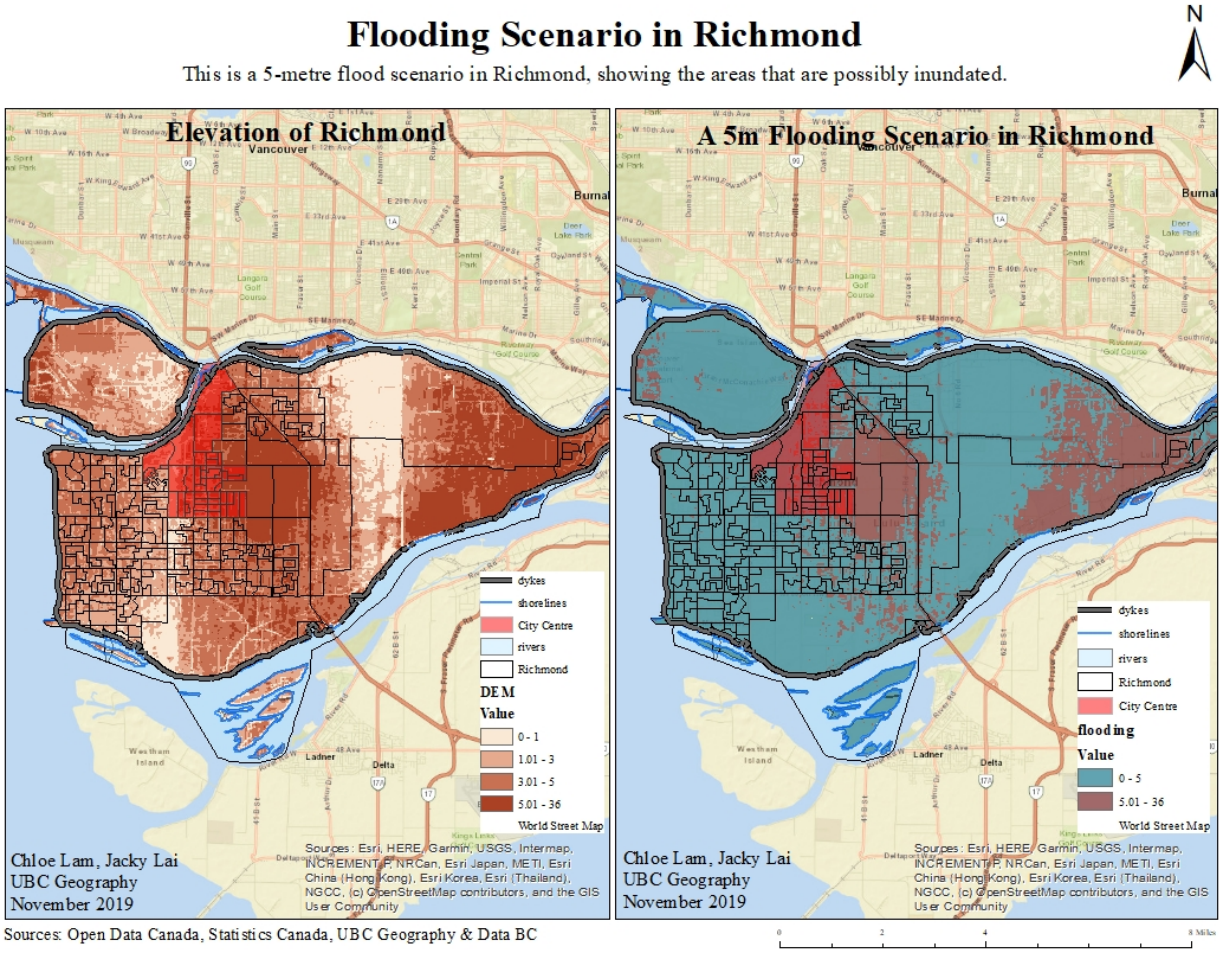
ii. 4 Maps & Figures

Map 1: Vulnerability of Richmond towards natural hazards [Population & Private Household Values]

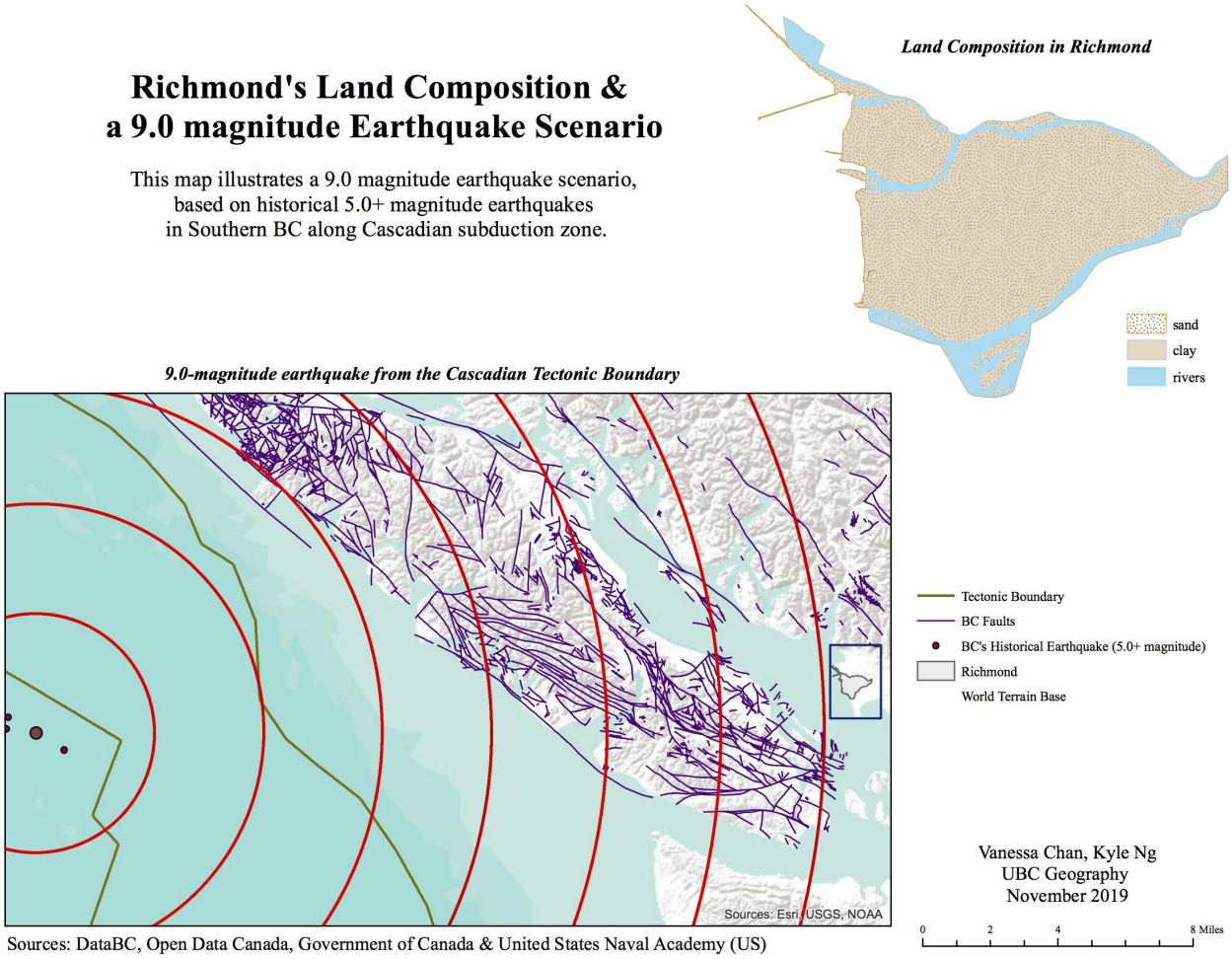


Sources: Data BC, UBC Data Services & Statistics Canada

Map 2: Elevation Levels & Potential Flood Risks in Richmond [a 5m flooding scenario]



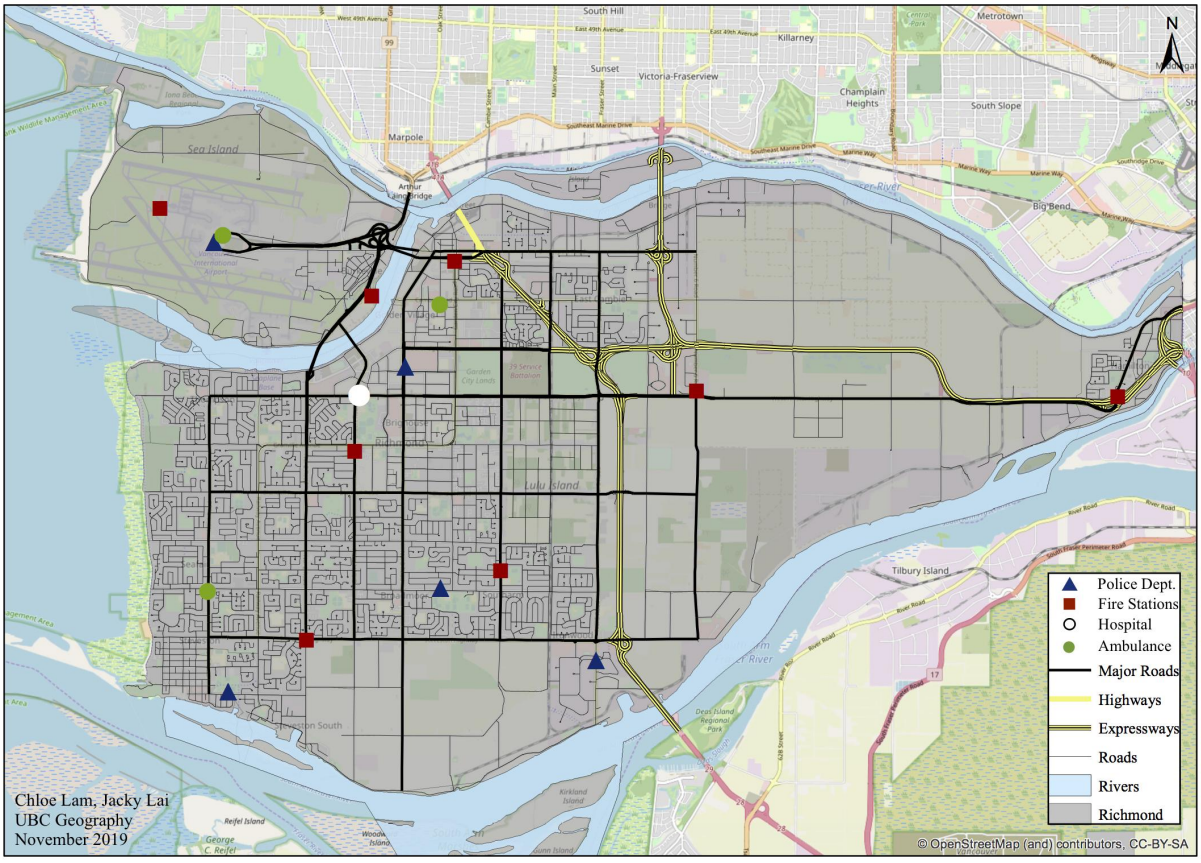
Map 3: Land Composition & a 6.0-magnitude Earthquake Scenario in Richmond



Sources: DataBC, Open Data Canada, Government of Canada & United States Naval Academy (US)

Map 4: Disaster Preparedness - Public Safety Services, Major Roads & Highways in Richmond

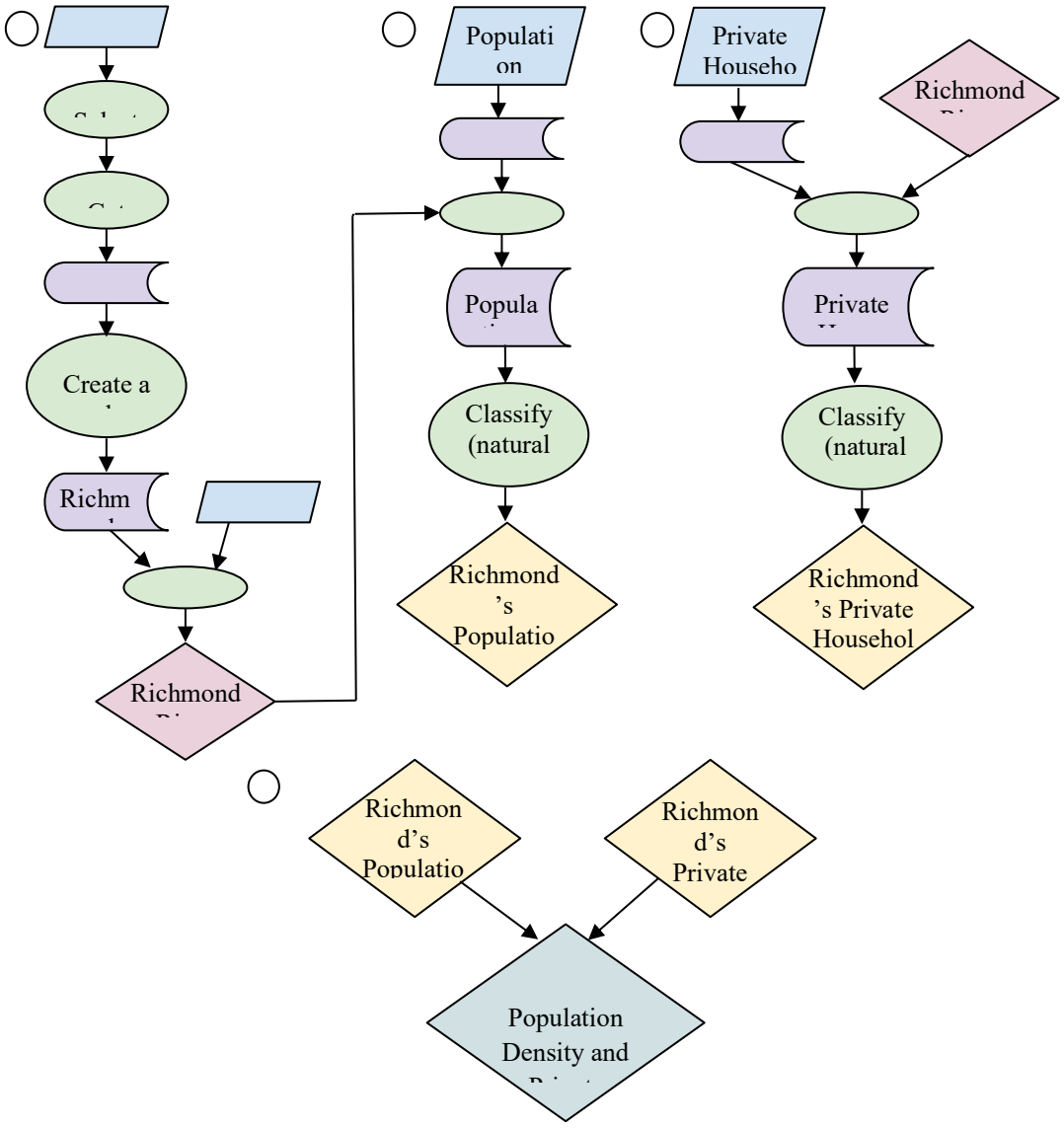
Public Safety Services, Major Roads & Highways in Richmond



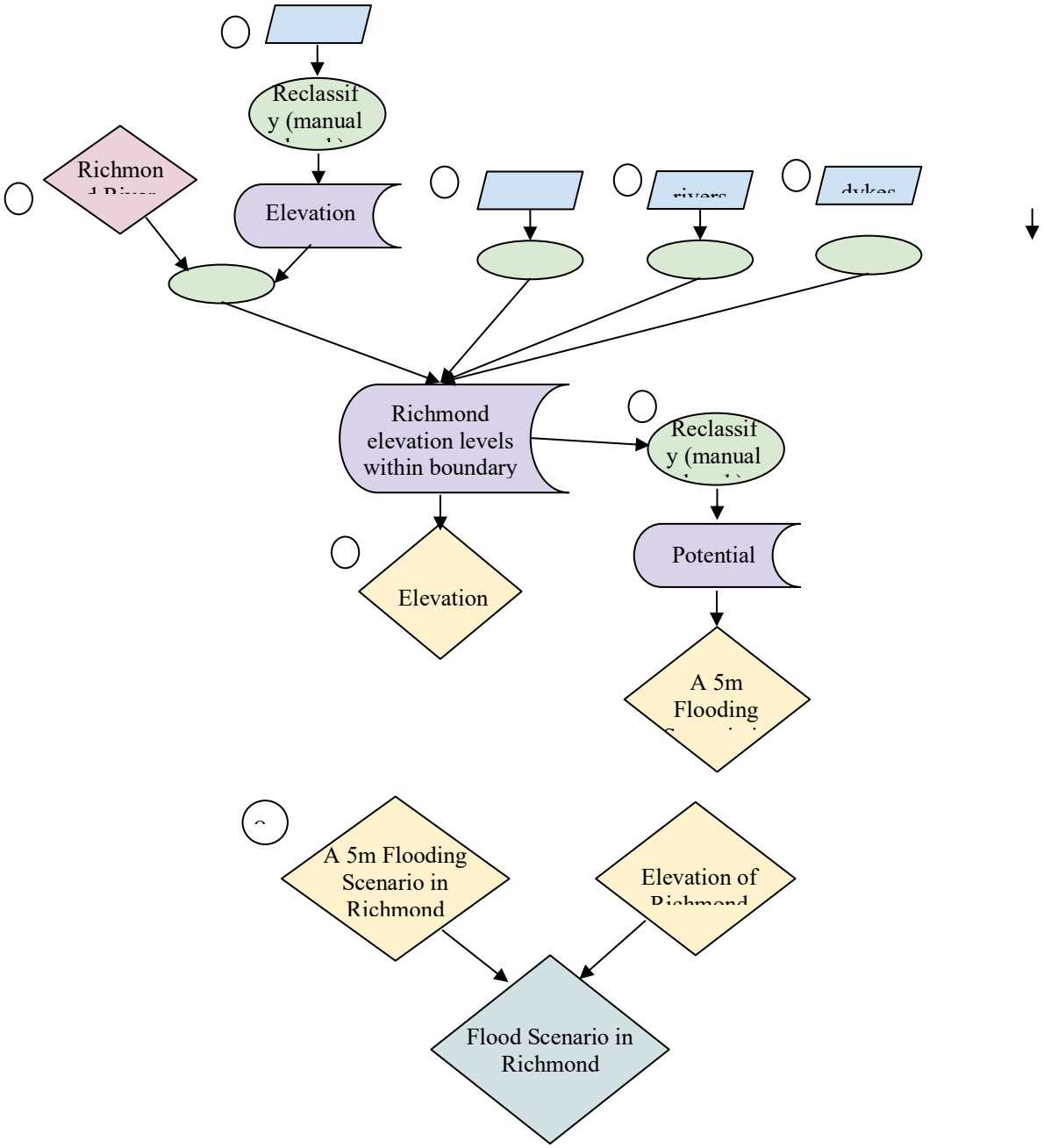
Sources: City of Richmond & CanMap

iii. Flowcharts

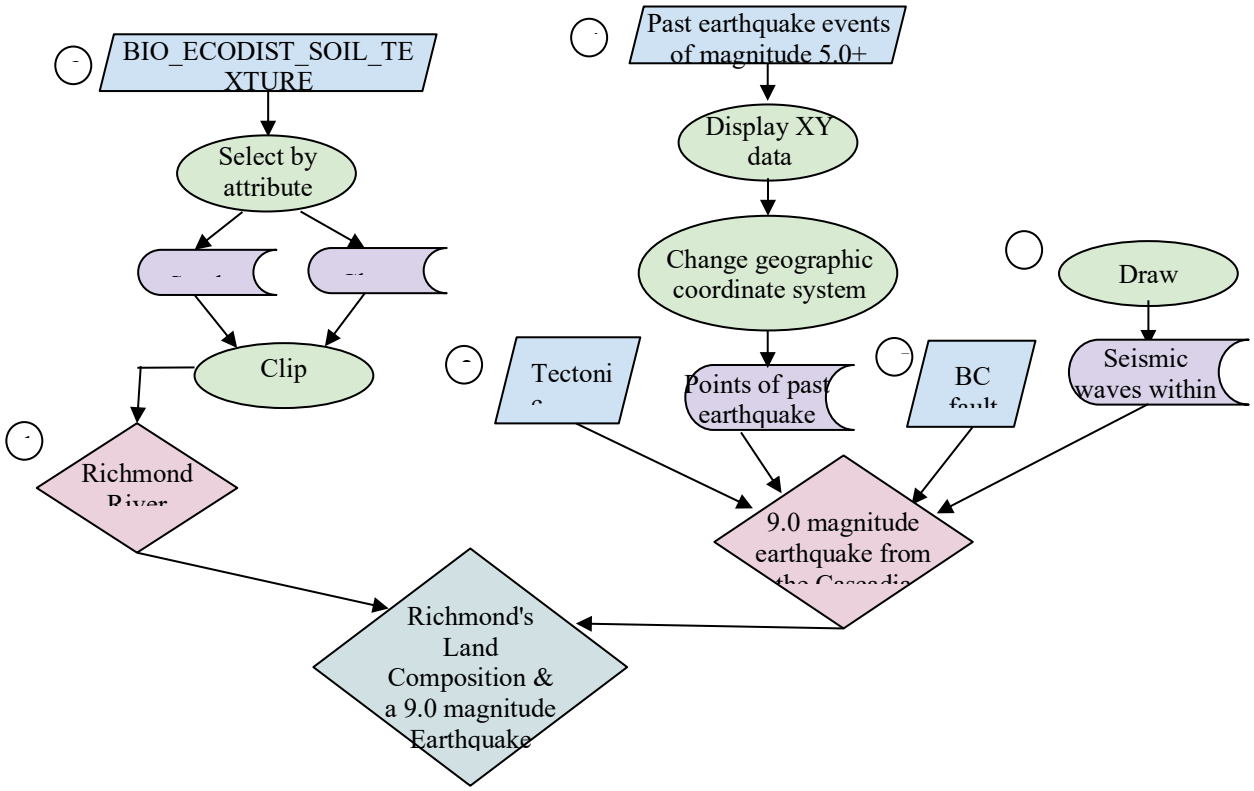
Map 1: Vulnerability of Richmond towards natural disasters [Population & Property Values]



Map 2: Elevation Levels & Potential Flood Risks in Richmond [a 5m flooding scenario]



Map 3: Land Composition & Earthquake Intensity in Richmond



Map 4: Disaster Preparedness - Public Safety Services, Major Roads & Highways in Richmond