Flood Risk Across the City of Vancouver

Flood Hazard Assessment

GEOB 270: Introduction to Geographic Information Systems

Final Project Report

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TABLE OF CONTENTS

ABSTRACT

In a combined sewer system (CSS), both wastewater and stormwater runoff are carried in a single pipe, and the contents are taken to wastewater treatment plants during dry conditions. For periods of heavy rainfall, high volumes of stormwater may exceed the system's carrying capacity, leading to excess untreated overflow into nearby waterbodies or waterways (Separating Sewage). Metro Vancouver is currently working to replace the combined sewers with separate sanitary and storm sewers throughout Vancouver, British Columbia, to achieve the province's goal of having separated sewer systems in all buildings by 2050 (Maintains the Water and Sewer System). This report will examine the hazardous effects of floods from CSS in the City of Vancouver. A vulnerability assessment map was used to visualize the flood interactions with neighbourhood type, population density, and sewer types. The data was gathered from the City of Vancouver's online database and the UBC Department of Geography's internal database. Discussions and interpretations from our results focus on the potential impacts that flood risks from the CSS will have in areas of Vancouver. From our analysis, we determined that East Vancouver as well as specific neighbourhoods such as Downtown Vancouver and Kitsilano tend to display higher risk categories of vulnerability. Proposed suggestions for allocating resources, reducing damage, and areas of high concern are made based on the findings.

DESCRIPTION OF PROJECT, STUDY AREA, AND DATA

As seen from previous incidences, Vancouver remains susceptible to localized flash flooding from heavy rainfall as certain drainage systems cannot handle sudden accumulation of high volumes of water, leading to excess, untreated amounts overflowing and emptying directly into our waterways (City of Vancouver, "Separating Sewage"). Consequently, high costs and time are required for damage repair, employing fire departments, and municipal water work crews for attending flooding and storm drainage backups. Moreover, basement flooding, traffic disruptions, further drainage and sewer problems, potential water contamination in flood areas and unexpected raw sewage discharge into the Burrard Inlet and Strait of Georgia have been reported (Government of British Columbia; Sinoski).

According to the City of Vancouver, this issue arises from the overcapacity of stormwater runoff in the combined sewer systems (CSS). Despite the fact that a few neighborhoods have separated sewer systems (SSS), many CSS are yet to be replaced. The City has identified five neighbourhoods to receive this SSS update by 2020 (City of Vancouver, “Separating Sewage”). Even so, only 60% of the communities will have SSS by this period (Crowe 2016).

This vulnerability assessment is derived using a GIS analysis to determine the flood vulnerability from CSS of Vancouver. The criteria for assessing vulnerability includes population density, land slope, neighbourhood type, land use type, zoning districts, surface catch basins and underground sewer systems. Data was retrieved from two primary sources, including the official City of Vancouver data catalogue and the UBC Department of Geography’s internal database.

By gathering information available by the city, we will use this analysis to determine the areas near storm catch drains with CSS that require additional effort or monitoring during heavy periods of rainfall. For instance, districts with higher population densities affected, may help the city allocate mitigation and management actions more effectively. By using buffering distances around known areas with storm catch drains above CSS than those with separated mains, potential flooding area buffers will allow us to create a visual map presenting normalized values of variables falling within these buffers, indicating the distribution of flood risk areas across Vancouver.

METHODOLOGY OF ANALYSIS

We decided to use the multi-criteria evaluation (MCE) method to determine the high risk areas within our project boundary, the City of Vancouver. We chose to limit our project boundary to a relatively small area due to the time restriction, availability of data, and mainly the familiarity of the general layout and characteristics of neighbourhoods within Vancouver. This will be able to validate the spatial data from our GIS model to our knowledge about the city. In order to use the MCE, we first agreed upon the ranking/reclassification scheme of the levels of risk, as well as how each layer would be weighted in its contribution to the final evaluation of risk, such as sewer systems, slope, population density, and zoning districts.

Starting with a catch basin layer, we wanted to show how these surface points were associated with different underlying sewer main types (CSS and SSS). To do so, we created a buffer of 15m around both the polylines of the CSS and SSS then intersected each of these with the catch basins that were buffered by 5m. We gave these intersected polygons different coloured symbology to assess the distribution across Vancouver and as suspected, the majority of catch basins were located above combined sewer systems. We also noticed a trend in Downtown Vancouver, where a vast majority of storm sewer basin attachments were in line with City of Vancouver data, detailing that most of the CSS had been replaced into a separated system in this area. The process of organizing and editing the data related to the sewer systems and catch basins was the most important part of the analysis as it was the main issue we focused our flood risk analysis around. By knowing the extent of the flood, we would be able to continue analyzing other risks and hazards associated with the flood.

Our DEM layer was reclassified by dividing the degree of slope into five equal interval classes with the lowest slope class given the highest risk and value of 5. The zoning district layer held nine categories of land use type that were aggregated into 5 classes by creating a new column in the attribute table and assigning values of 1 to 5 for risk. The population shapefile was divided into 5 classes of natural breaks and reclassified with the highest density population given a value of 5 for high risk.

Next, the 5 layers were converted for the sake of compatibility, using the polygon to raster tool (with default pixel size of 42) in order to input these layers into the raster calculator tool. Since each cell has already been previously normalized by a ranking value from 0 to 5, we wanted to weigh each layer equally. We decided that the raster calculator would be the most efficient way of combining our layers for our final map.

DISCUSSION AND RESULTS

We began our project with the hypothesis that areas with a combination of high population density, housing, and low slope will be at highest risk of damage in the case of flash floods due to overwhelmed combined and storm sewer systems. Using a multi-criteria evaluation (MCE) we created a map displaying the distribution of risk from sewage overflow as a result of these variables of vulnerability. From this, we were able to compare our results with the neighbourhoods the City of Vancouver identified with replaced CSS, and neighbourhoods with future sewer replacement plans, which should be low and high risk areas respectively.

According to the City of Vancouver, separating stormwater from wastewater is beneficial for several reasons, including using stormwater as a resource and more importantly, eliminating sewer overflow and preventing flooding by increasing capacity. During drier weather, stormwater and wastewater are carried to the sewage treatment plant together. However, during heavy rain events, high volumes of stormwater can exceed the capacity of a CSS and the resulting overflow poses socioeconomic risks to the population. Increased water levels may cause damage to private properties such as businesses and homes, while the overflow of wastewater may cause contamination and pose a health risk to the population.

Appendix D shows the distribution of sewer structure types across the City of Vancouver. It is important to note that before using this factor in our raster calculation this layer underwent an intersection with catch basin points since surface flooding only occurs where there is an exit point for overflow. This map however, does show a clear divide in one of the major factors involved in our analysis. The perimeters of Vancouver tend to have SSS (shown in blue) whereas the majority of the area inland (shown in red) consists of CSS. As a focus area for sewer system upgrades due to to increased growth, the Grandview neighbourhoods is an ongoing project at 85% completion (July 2016), with less CSS expected (Separating Sewage from Rainwater).

In our analysis, we attributed the three types of dwellings (one-family, two-family, and multi-family) in the Downtown Vancouver area the highest risk value of 5 as we considered the impact to dwellings the most pressing in terms of damage resulting from sewage overflow, rather than potential economic losses in the case of a localized flash flood. Comprehensive development zones were given a risk value of 4 (just below dwellings) as certain areas, such as Downtown Vancouver have a relatively high housing density in addition to other land uses such as commercial buildings. Industrial zones were ranked at 3, and light industrial and commercial zones at 2, since these zones would likely incur an economic loss, though not a critical issue relative to housing damage. Historical areas and agricultural zones were given the lowest value of 1 as they do not have a significant impact on people's livelihood since agricultural areas such as southwest Vancouver do not contain many sewer mains to overflow from (See Appendix D), which is likely due to low population density (See Appendix C). By taking into account that most of Vancouver's food supply is not locally sourced, damage to crops from overflow would not have a significant impact on the population. When we selected historical areas in our data, there were only a few small points in Vancouver, some being in Downtown Vancouver. This category may represent some heritage buildings found Downtown, thus giving it the lowest ranking as we did not consider these as housing or economic factors that would be an immediate impact to the safety and well-being of the population.

We also weighed population density in our analysis of risk from sewage overflow. There were two main motivations for including this layer. One being that the we wanted to observe the distribution of the amount of people that could be affected by flooding. The other ties into the overarching problem of the structure of the existing combined sewer systems. They are ineffective because sanitary waste and storm water runoff are collected in the same sewer mains under the city. A higher population density in an area might also correlate with higher sanitary waste being produced and a greater potential for the CSS to reach capacity more quickly during significant rainfall than in an area with lower population. In Vancouver, the population tends to be more densely concentrated in the East and around the Burrard Inlet in neighbourhoods such as Kitsilano and Downtown (See Appendix C).

Another criteria for vulnerability to the effects of sewage overflow we considered was the degree of slope of the topography of the city. The Digital Elevation Model (DEM) was used for this purpose and reclassified into 5 risk categories. The areas with the lowest degree of slope would be given the highest risk value of 5 because these areas would be least efficient at directing water away and thus water tends to collect in these low lying areas. The areas in Vancouver with the highest degree of slope would be given the lowest risk value of 1 since sewage overflow is likely to dissipate most quickly in these areas of steep terrain. However, when we input the DEM into the slope tool and looked at the data, a significant amount of the slopes was less than 45°, especially 20° and lower (See Appendix A). We decided that the slopes were so low that the difference between 20° and 10° would not significantly affect our final results, therefore we assumed a homogeneous or flat surface for the sake of this analysis.

Overall our MCE resulted in a varied degree of risk across Vancouver as well as within each neighbourhood. This is to be expected as we took several variable into account and these variables differed on the large scale and within smaller neighbourhood scale. There was a general spatial trend of less low risk areas in the East portion of Vancouver compared to the West. This trend wasn’t significant, but might derive from higher population density in less affluent neighborhoods and more land use for housing. Some areas of high risk on our final map that were classified as high risk might initially seem to disagree with the City of Vancouver’s analysis since they are not included in the outlined areas with higher risk sewer systems. One such area is Downtown Vancouver, where there is one of the highest densities of population in Vancouver (See Appendix C). Due to this density there is also a large portion of land attributed to housing in the form of apartments. These factors combined with low slope would result in the area being classified as high risk in our analysis. However this area has already been classified similarly by the city since it is one of the areas of the most extensive sewer separation (See Appendix D). This leads us to believe that population density likely influenced the city’s decision making process for the replacement of CSS.

Four of the five neighbourhoods outlined as areas to have CSS replaced as SSS by 2050, dictated by the City of Vancouver are outlined in our final map (See Appendix E). The Sunrise area was not delineated in our map since the zone included Hastings and Sunrise in our layer and Hastings was a neighbourhood that had already been targeted with upgrades to separate sewer systems. These four neighbourhoods did not show a high population density relative to the rest of Vancouver (See Appendix C). This resulted in risk mostly ranging from low to medium and rarely reaching very high risk. These neighbourhoods do however, display a large coverage of housing as land use and do contain some coverage of CSS within their boundaries (See Appendix D). This suggests that the City may take land use into account and prioritize areas of dense housing as we did in our analysis. Perhaps this area is considered at a higher risk in the City's view than our analysis because they weighed land use more heavily than population, having already targeted the high population zones for replacement or this may suggest other factors were taken into account that were overlooked in our analysis.

It is also important to note that risk was not able to be classified across the entirety of the city. Data was not available for certain areas such as land falling within the University of British Columbia or Stanley Park. This does not imply zero risk in this areas, but rather no data. Other areas in our map that don't fall under our range of risk symbology and appear grey like the base map colour, such as rectangles throughout Vancouver, might be parks or large establishments where census tract population data may have been unavailable (See Appendix E).

ERROR AND UNCERTAINTY

There were certain areas of this project, research or technical, that may have produced errors and uncertainty, stemming from our interpretation and a lack of metadata. For example, while exploring population density, there was no immediately available metadata to aid in understanding the attribute table or the other components. Hence, our own interpretations from other sources were made. Though all the data was collected from reliable sources, factors like these allowed for uncertainty in determining the affected flood risk parameters.

The lack of precise data also causes uncertainty. Namely, we lacked data for water bodies (e.g. rivers, lakes, etc.), and discounted shorelines. Their presence may have altered our results, due to risks of rising water levels from severe storms, and flooding onto adjacent land. While these water bodies may have increased risk in certain areas, they might also have the ability to mitigate risk in others by redirecting storm drain overflow into natural waterways. The complexity of this factor is why we excluded it.

Additionally, we did not considered the permeability and shear strength of various land types (e.g. Roads, gardens, parks, pavement, etc.). This would provide a new dimension to our research, as it includes the level of damage excess water flow can enact on the structure it flows onto. Also, methods that neighbourhoods may practice in order to mitigate flood risk were not included; namely the presence of on-site storage of rainwater, or integrated stormwater management strategies (Minimizing Flooding).

Moreover, while diameter and material type attribute data was available for the sewer systems, the total capacity of combined sewer and storm sewers were not considered as we were unaware of the volume of precipitation needed to reach the threshold where storm drains begin to overflow. Each catch basin was thus given an equal probability when, in fact, this is unlikely.

In a GIS aspect, projecting a 3D world into 2D will inevitably produce fundamental errors, as there is no way to perfectly replicate our world onto a 2D plane (Walker). Also, we could have produced errors while reclassifying our main layers to produce the “1 to 5 risk value”. For example, in the population layer, we selected the classes ourselves, and chose the high and low risk densities. The same variety of error may have been produced when we chose which land-use types would produce high risk. Human error may exist due to our interpretation of data, and the observations of our dataset (ex. Roads, land-use type, zoning, DEM slope). There is also the possibility of unnoticed minor technical errors on GIS. Lastly, we focused primarily on Metro Vancouver, and did not consider surrounding cities and neighbourhoods. These areas may, in reality, contribute towards the flood risk of our area in question.

Even though these errors or uncertainties may alter our results, we strongly believe that the data chosen and GIS practices used for this project enabled us to create a map that still allows us and viewers to see which areas are under the highest flood risk. This can then be used in the future to conduct more detailed flood risk analysis and suggest mitigation methods.

FURTHER RESEARCH AND RECOMMENDATIONS

Based on our results, various areas around Metro Vancouver are at a higher risk for flooding. Two recommendations to protect the populations at risk is to invest in further research and implement additional policies. The city can require improving and investing in urban green space and infrastructure to reduce impermeable surfaces. Moreover, residents within high risk areas may be notified, and provided with resources and opportunities for potential flood risk preparation. This may occur through ensuring homeowners and building managers of replacing old sewage pipes with ones better suited for bad weather conditions (Minimize Flooding). Additionally, educating homeowners to clear storm drains and catch basins, by removing leaves and debris will reduce poor drainage (Minimize Flooding). The local municipality should make efforts to reinforce and ensure these policies are practiced.

As a major issue increasing over the past few decades, climate change correlates to rising incidences of flooding, and land surface temperature; leading to higher rates of evaporation, condensation and precipitation (Rain and Snow; Scheifele). To combat flooding, additional research must be conducted on flood risk factors in relation to temperature change, greenhouse gas emissions and soil permeability. For instance, an analysis on temperature change and precipitation across a greater surface area such as Canada or North America may be compared to flooding risks similar to our research, using GIS. From these results, mitigation and adaptation techniques, such as emergency communication plans, elevating furnaces and electrical panels, sealing walls, and installing ‘checking valves’ may minimize the level of risk overtime.

Modelling flood risk is complex and causes uncertainty, and sensitivity analyses is crucial due to the lack of data from the short time frames of heavy rainfall. This includes varying the number of risk categories within elevation slopes and population density. A better understanding these features will also provide a more accurate representation of regions at risk, in order to target the issues at hand.

Combining research efforts, disaster mitigation strategies and developing public policies is economically and politically feasible, and necessary to prepare for future impacts of flood risk.

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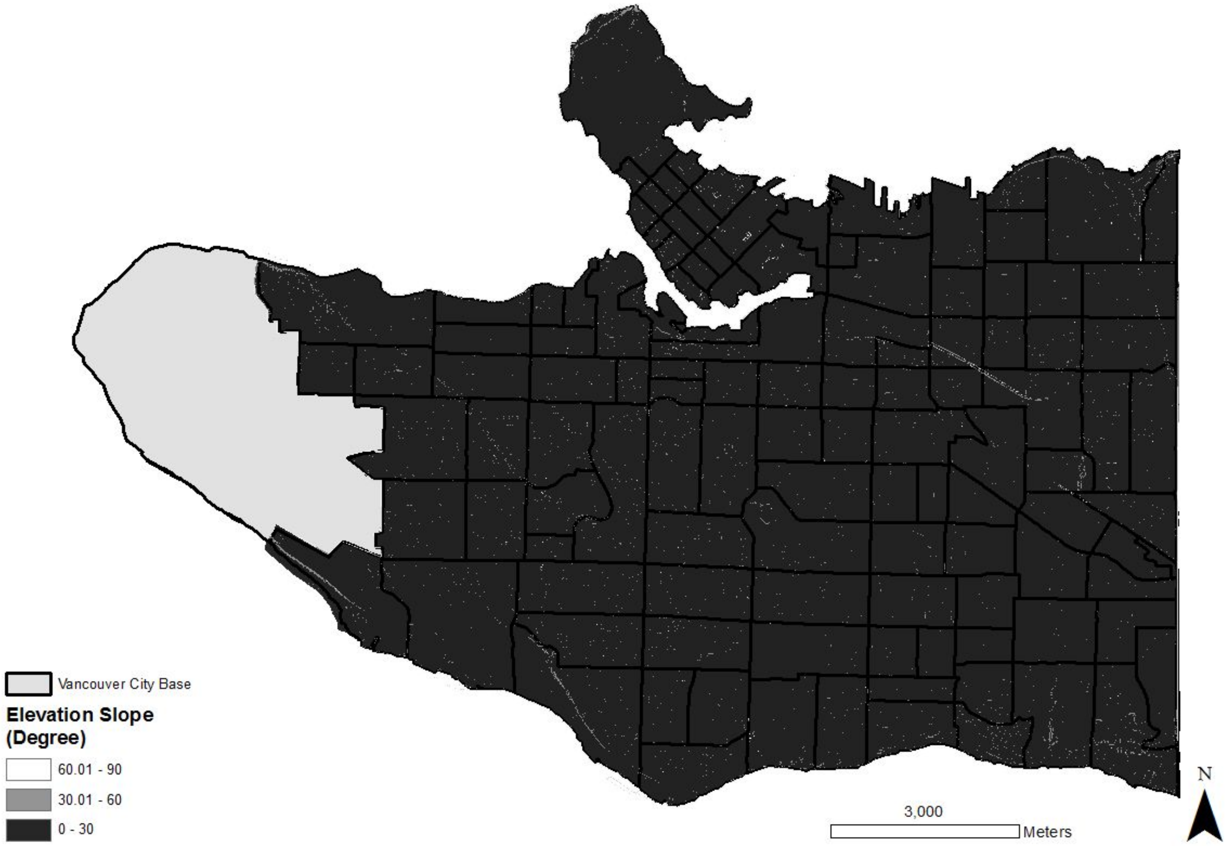
APPENDIX

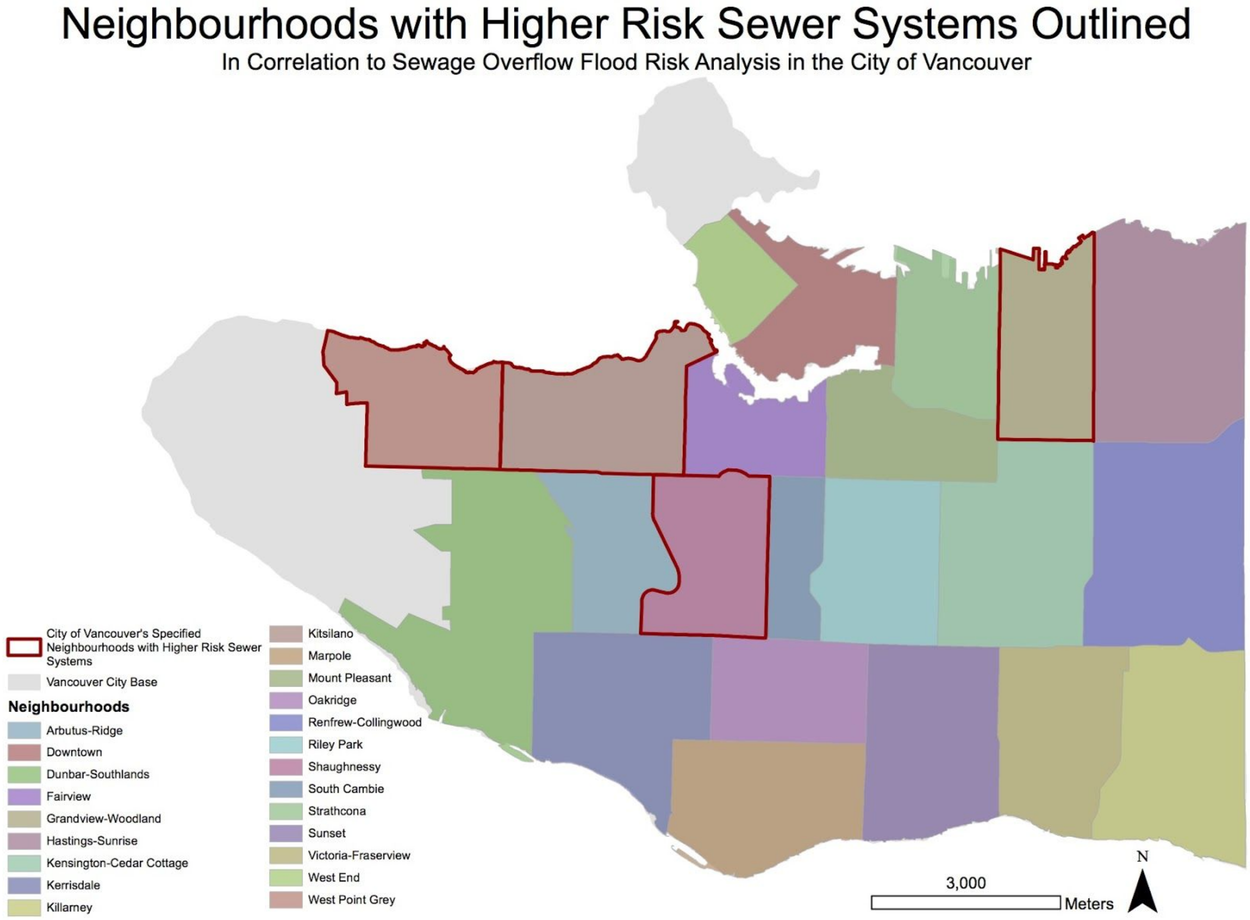
Appendix A: Digital Elevation Model recalculated to determine the elevation slope.*



Data source: Digital Elevation Model (2013).
http://data.vancouver.ca/datacatalogue/digitalElevationModel.htm

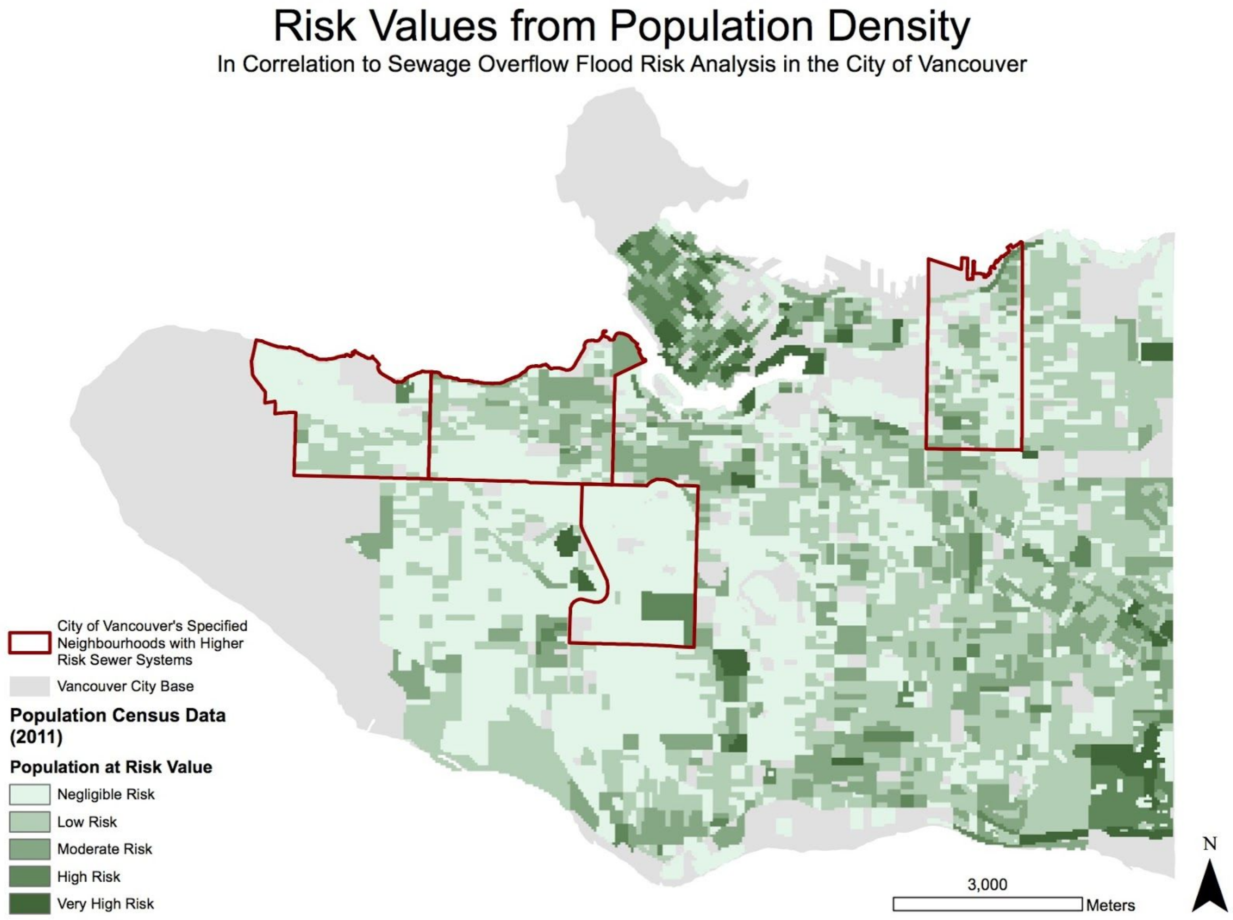
*A figure, not considered a map in our analysis

Appendix B: Sewer systems with the highest risk in the 22 local areas as defined by the City of Vancouver



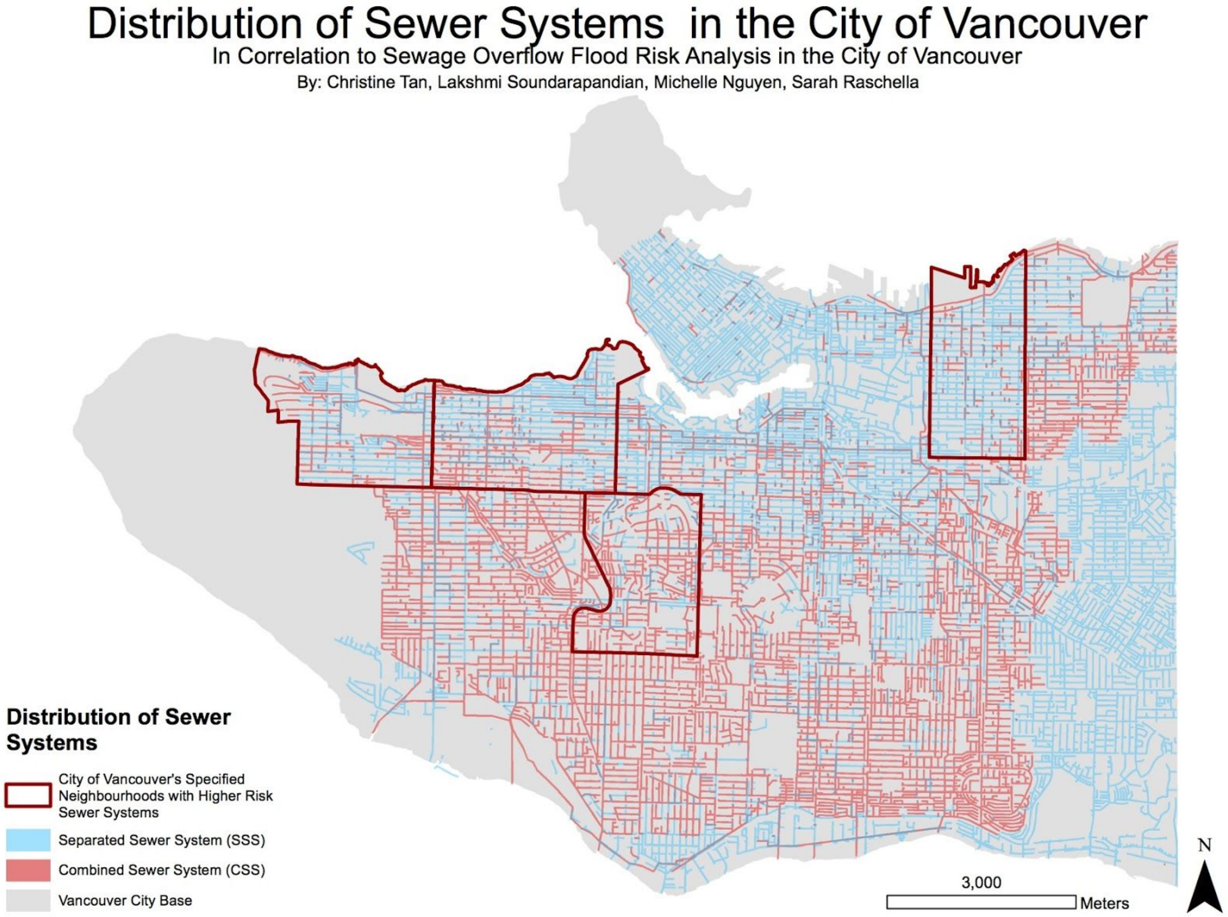
Data Source: Local Area Boundary.
http://data.vancouver.ca/datacatalogue/localAreaBoundary.htm

Appendix C: Population census data based classified into five risk categories from the demographic and behavioral population



Data source: Census Local Area Profiles (2011). http://data.vancouver.ca/datacatalogue/censusLocalAreaProfiles2011.htm

Appendix D:

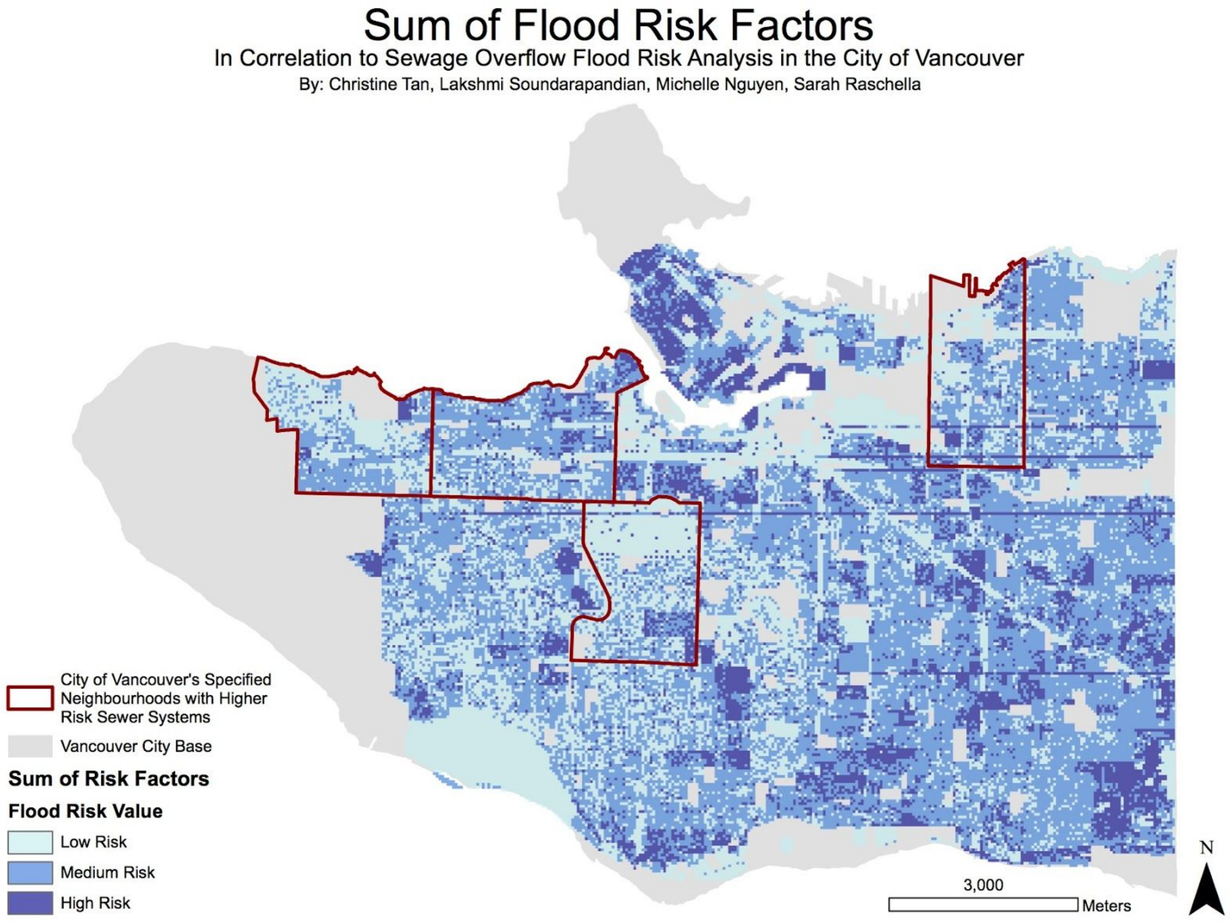


Data Source:

Sewer Network Data Package.

http://data.vancouver.ca/datacatalogue/sewerNetwork.htm

Appendix E: Risk factors calculated from the classified risks in the sewer systems, population density, and zoning districts with high risk sewer systems defined by the City of Vancouver outlined.



Data source:

Census Local Area Profiles (2011).
http://data.vancouver.ca/datacatalogue/censusLocalAreaProfiles2011.htm

Sewer Network Data Package.

http://data.vancouver.ca/datacatalogue/sewerNetwork.htm

Zoning Data Package.

http://data.vancouver.ca/datacatalogue/zoning.htm

Appendix F: Neighbourhoods in Vancouver with and without separated sewer systems (SSS), which separate stormwater from wastewater. These coincide with

Appendix F.

*Neighbourhoods **with** SSS*	*Neighbourhoods **without** SSS*
Downtown	Grandview
West End	Kitsilano
Fairview	Point Grey
Hastings	Shaughnessy
Killarney	Sunrise*
Mt.Pleasant	
Renfrew	
Burrard Inlet and Fraser Valley Shorelines	

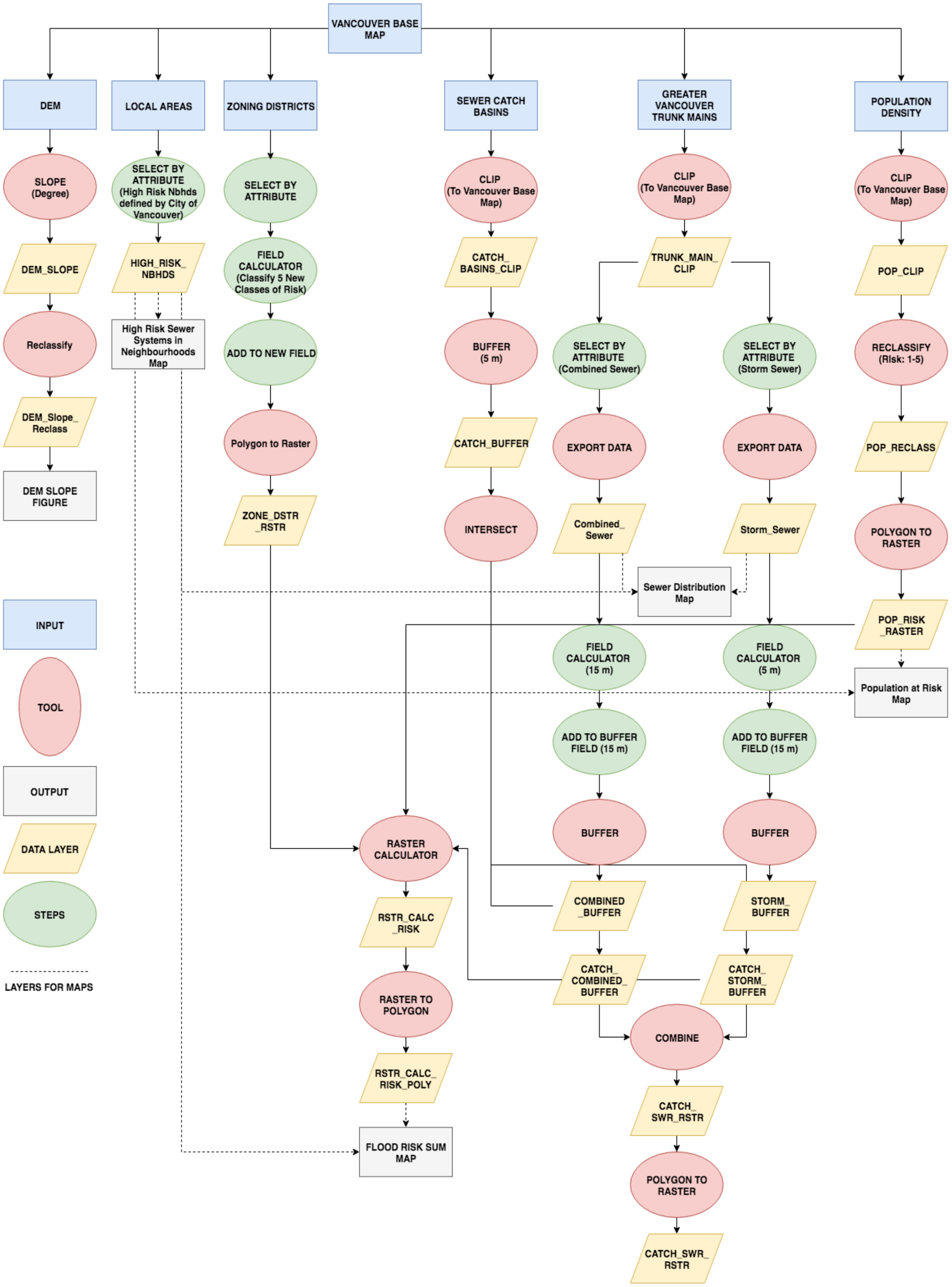
*Not outlined in Appendix B due to this neighbourhood being aggregated with Hastings in our neighbourhood layer.

Data Source:

Separating Sewage from Rainwater.

http://vancouver.ca/home-property-development/separating-sewage-from-rainwater.aspx

FLOW CHART


VANCOUVER BASE MAP
DEM
LOCAL AREAS
ZONING DISTRICTS
SEWER CATCH BASINS
GREATER VANCOUVER TRUNK MAINS
POPULATION DENSITY
SLOPE (Degree)
SELECT BY ATTRIBUTE (High Risk Nbhds defined by City of Vancouver)
SELECT BY ATTRIBUTE
CLIP (To Vancouver Base Map)
CLIP (To Vancouver Base Map)
CLIP (To Vancouver Base Map)
DEM_SLOPE
HIGH_RISK_NBHDS
FIELD CALCULATOR (Classify 5 New Classes of Risk)
CATCH_BASINS_CLIP
TRUNK_MAIN_CLIP
POP_CLIP
Reclassify
High Risk Sewer Systems in Neighbourhoods Map
ADD TO NEW FIELD
BUFFER (5 m)
SELECT BY ATTRIBUTE (Combined Sewer)
SELECT BY ATTRIBUTE (Storm Sewer)
RECLASSIFY (Risk: 1-5)
DEM_Slope_Reclass
Polygon to Raster
CATCH_BUFFER
EXPORT DATA
EXPORT DATA
POP_RECLASS
DEM SLOPE FIGURE
ZONE_DSTR_RSTR
INTERSECT
Combined_Sewer
Storm_Sewer
POLYGON TO RASTER
Sewer Distribution Map
POP_RISK_RASTER
INPUT
FIELD CALCULATOR (15 m)
FIELD CALCULATOR (5 m)
Population at Risk Map
TOOL
ADD TO BUFFER FIELD (15 m)
ADD TO BUFFER FIELD (15 m)
OUTPUT
RASTER CALCULATOR
BUFFER
BUFFER
DATA LAYER
RSTR_CALC_RISK
COMBINED_BUFFER
STORM_BUFFER
STEPS
CATCH_COMBINED_BUFFER
CATCH_STORM_BUFFER
LAYERS FOR MAPS
RASTER TO POLYGON
COMBINE
RSTR_CALC_RISK_POLY
CATCH_SWR_RSTR
FLOOD RISK SUM MAP
POLYGON TO RASTER
CATCH_SWR_RSTR