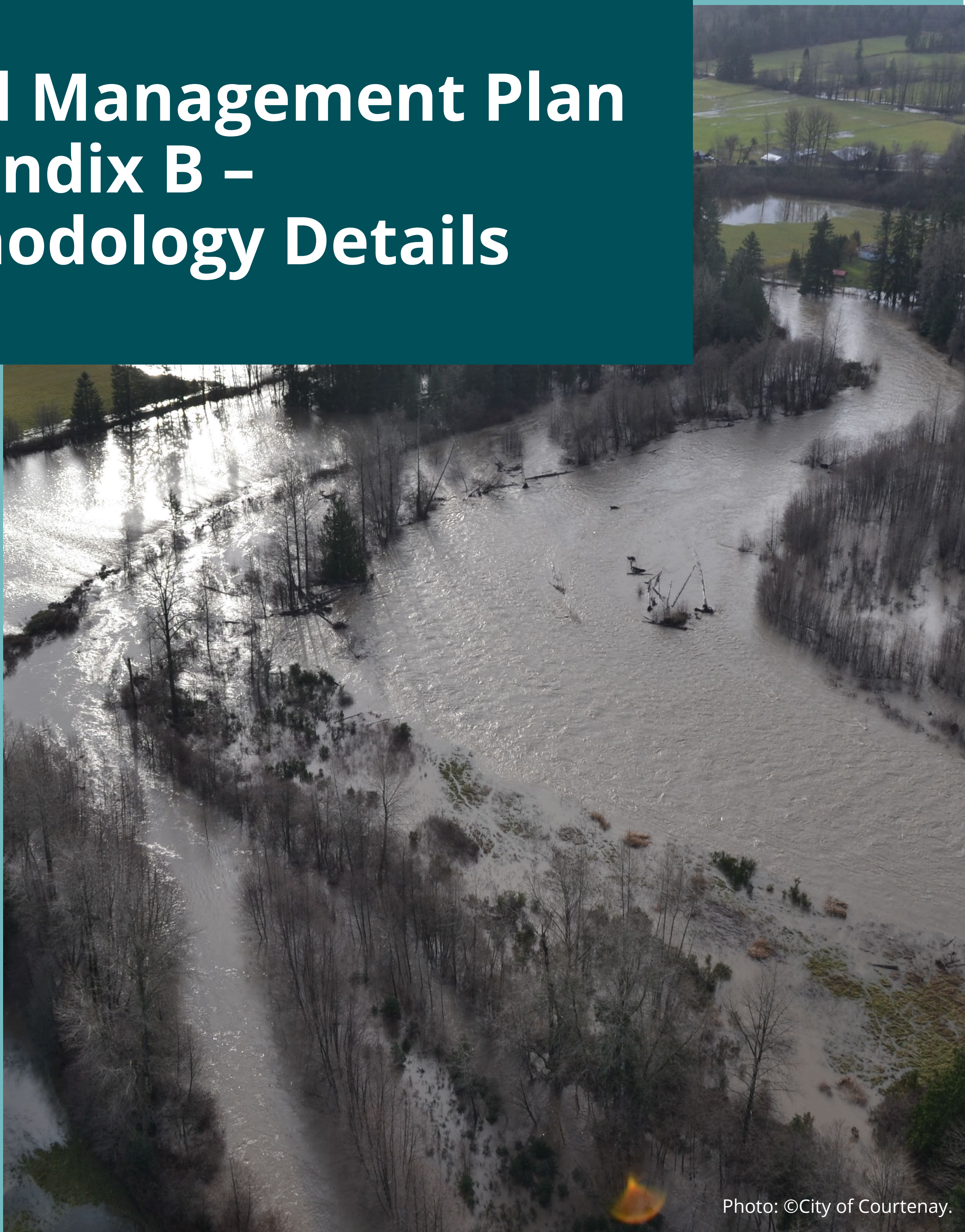
City of Courtenay

Flood Management Plan Appendix B – Methodology Details



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List of Abbreviations and Acronyms

Acronym/Abbreviation	Description
AAFC	Agriculture and Agri-Foods Canada
AAL	Average Annual Loss
ACI	Annual Crop Inventory
AEP	Annual Exceedance Probability
AIDR	Australian Institute for Disaster Resilience
ALR	Agricultural Land Reserve
BC	British Columbia
BCA	British Columba Assessment
CDD	Canadian Disaster Database
CI	Critical Infrastructure
CVRD	Comox Valley Regional District
CGVD2013	Canadian Geodetic Vertical Datum of 2013
DA	Dissemination Area
DEM	Digital Elevation Model
EAD	Expected Annual Damage
EV	Electrical Vehicle
FCL	Flood Construction Level
FMP	Flood Management Plan
FRA	Flood Risk Assessment
GIS	Geographical Information System
ICI	Integrated Cadastral Information (Society)
KFN	K'ómoks First Nation
KWL	Kerr Wood Leidal Associates Ltd.
LiDAR	Light Detection and Ranging (remote sensing method)
NRCan	Natural Resources Canada
SLR	Sea Level Rise
SVI	Social Vulnerability Index

1 Introduction

The City of Courtenay (City, Courtenay) initiated a Flood Management Plan project and retained Ebbwater Consulting Inc. (Ebbwater) and its team to conduct this work. The main report (Ebbwater Consulting Inc., 2024) [1] provides information regarding project goals, risk and resilience background, project area background, flood management plan approach, risk assessment results, option analysis, and recommended flood management strategies.

This Appendix B provides methods for the flood risk assessment (Chapter 2), followed by detailed description of processing of British Columbia Assessment (BCA) data and land parcels for input into the risk assessment (Chapter 3). Lastly, the appendix provides supporting information for the option analysis, with focus on calculation of risk reduction performance measures (Chapter 4). This is followed by conclusions (Chapter 5) and references (Chapter 6).

The following attachments provide further details:

- Attachment 1 - Risk Assessment Results: tabulated raw data/results of the risk assessment, including Average Annual Losses (AALs) of the baseline ('do nothing') option (spreadsheet).
- Attachment 2 – Spatial data package, including hazard and consequence datasets for the likely present-day and less likely mid-term future scenarios.

Further, note that Appendix C provides a set of consequence maps for the present-day - likely and mid-term - less likely future scenarios.

[1] Ebbwater (2024): City of Courtenay Flood Management Plan. Prepared for the City of Courtenay.

2 Quantitative Risk Assessment Methods

The following sections provide details on the quantitative flood risk assessment. More specifically, they describe the hazard and consequence data (including confidence rating), explain the development of risk curves and calculation of total risk, and cite the data processing software used for the risk assessment.

2.1 Flood Hazard Data

A set of flood hazard scenarios from the Phase I Comox Valley Regional District (CVRD) Coastal Flood Mapping (Kerr Wood Leidal Associates Ltd., 2021) data was used for this project. A summary of the data is presented in the following sections, with brief discussion of limitations relevant to our scope of work.

2.1.1 Hazard Input Data

The first step in understanding risk is the identification of areas affected by flood hazards for a range of likelihood and climate scenarios. Phase I CVRD Coastal Flood Mapping report (Kerr Wood Leidal Associates Ltd., 2021) mapped 21 combined riverine and coastal flood scenarios for the Courtenay River system and Comox estuary (including one proposed flood protection works scenario[2]). After reviewing the datasets and scenarios, 20 riverine and coastal scenarios (combinations of four time periods and five likelihoods), that included the existing flood protection works, were selected for the flood risk assessment (Table 2-1), ensuring that risk results are based on a robust range of scenarios.

The 20 flood hazard scenarios range from 10% Annual Exceedance Probability (AEP) to 0.2% AEP flood (Table 2-1). The 10% AEP flood is meant to represent a flood that would have occurred in the recent memory of the community members. In contrast, the 0.2% AEP flood is a very large but rare event. The flood hazard scenarios take both coastal and riverine conditions into account. The scenarios consider the occurrence of a riverine and coastal event of the same likelihood at the same time (e.g., the likely (5% AEP) scenario considers a 5% AEP riverine peak flow, combined with a 5% AEP coastal storm surge)[3]. This is a very conservative estimate, but there could also be the case that a more

[2] The proposed flood protection works scenario included the 2013 Courtenay Integrated Flood Management Study flood protection option 2 (ring dike) (McElhanney Consulting Services Ltd., 2013) and raising of the Highway 19A (Kerr Wood Leidal Associates Ltd., 2021).

[3] I.e., a joint-probability approach, where a range of different coastal storm surge and riverine peak flow probabilities are combined, was NOT applied in the 2021 flood hazard mapping project. The limitations of this approach combination are now replicated for this project.

extreme (lower probability) event of one flood hazard would occur in combination with a higher probability event of the other. Alternatively to this approach (of assuming that a riverine and coastal event of the same likelihood occur at the same time), the analysis conducted in the CVRD Coastal Flood Mapping report could have taken into account the joint behaviour of the two hazards. For example, assuming the two hazards are statistically independent, different combinations of riverine flows and coastal water level events with an AEP product matching the desired joint probability AEP could have been tested. In that case a combination of 5% AEP of coastal water levels and riverine flows would have yielded a 0.25 %AEP which has a substantially lower likelihood of occurrence. This type of analysis requires significantly more effort and resources, and was outside the scope of the 2021 regional flood hazard mapping project. And so, for this work we were constrained by the available information and the associated limitations.

A combination of sea level rise (SLR) projections of 0.0 m, 0.5 m, 1.0 m, and 2.0 m and a 0%, 15%, 15%, 30% increase in riverine flows, respectively, were considered for the five likelihood scenarios (Table 2-1, next page). While timelines are not explicitly associated with the scenarios, generally the planning range can be loosely linked to the present-day, the 2050s (near future), 2100s (mid-term future), and 2200s (long-term future), respectively. Note that coastal depths include an allowance for regional land uplift, or subsidence as appropriate minus the ground surface elevation at any point.

Table 2-1: Flood hazard layer scenarios and naming conventions for the risk assessment (coastal and riverine flooding).

AEP for River Flow and Extreme Ocean Level (Indicative Return Period)	Likelihood Qualifier	Sea Level Rise[4]	River Flow (% Increase with Climate Change)	Climate Scenarios
10% (1:10 years)	Frequent	0 m 0.5 m 1 m 2 m	0% 15% 15% 30%	Present-day Near Future Mid-term Future Long-term Future
5% (1:20 years)	Likely	0 m 0.5 m 1 m 2 m	0% 15% 15% 30%	Present-day Near Future Mid-term Future Long-term Future
1% (1:100 years)	Possible	0 m 0.5 m 1 m 2 m	0% 15% 15% 30%	Present-day Near Future Mid-term Future Long-term Future
0.5% (1:200 years)	Less Likely	0 m 0.5 m 1 m 2 m	0% 15% 15% 30%	Present-day Near Future Mid-term Future Long-term Future
0.2% (1:500 years)	Rare	0 m 0.5 m 1 m 2 m	0% 15% 15% 30%	Present-day Near Future Mid-term Future Long-term Future

2.1.2 Hazard Data Quality Assessment

In the Phase 1 CVRD Coastal Flood Mapping, water depth and water level raster data ("raw data") was produced for all scenarios. The water depth data depicts the maximum water depth and incorporated wave effects for coastal areas (i.e., not within the river channel). Although the raster format of the raw data is a suitable choice to store information such as depth and elevation, vector data ("processed

[4] Note that coastal depths include an allowance for regional land uplift, or subsidence as appropriate minus the ground surface elevation at any point.

data") are better suited to store spatial information related to extent and for the calculation of risk. KWL therefore also provided scenario flood extents, derived from the raw data in a vector format. The vector layers were simplified by KWL by removing any dry "islands" (areas that were surrounded by flood) that were smaller than 1,000 m^2 or were less than 3 m above the surrounding flood level on average. These filling criteria were applied to assume that small, low-lying areas would flood due to the surrounding flood conditions. These types of approaches to clean the data are common, however the thresholds used by KWL are substantially larger than those used in other similar projects (e.g., Northwest Hydraulic Consultants Ltd., 2019).

To ensure that the vector and raster datasets did not have substantial differences within the project area, we performed a visual inspection of the relevant layers. Our qualitative investigations showed that the differences between the raw (raster) and processed (vector) layers are generally small, with the latter providing slightly more conservative flood extents for the City of Courtenay. As the processed vector data is a simplified version of the raster layers, it is more usable and produces more easily comprehensible results in cases when only the flood extents are needed.

For the flood risk assessment, we used both the processed data and the raw data. More specifically, for discussing vulnerability where depth information was imperative, the raw data was used, whereas the processed data were used otherwise.

During the review of the hazard datasets, an inconsistency in the processed data was found for one scenario: The 0.5% AEP near future scenario was adjusted, as Canterbury Dike was shown to be overtopped and the area behind the dike flooded, but the following more extreme scenarios (i.e., the 0.2% AEP near future scenario etc.) did not show overtopping. The 0.5% AEP near future scenario (flood extent layer) was corrected to remove dike overtopping, to achieve consistency with the available depth data and other scenarios.

2.1.3 Hazard Data Limitations

Apart from the quality of the assessed layers, another important consideration is their relevant limitations. The flood hazard datasets were produced for a regional study (Kerr Wood Leidal Associates Ltd., 2021), and the results were generated separately for coastal and riverine areas, and later combined in one spatial layer per scenario. Due to the large area modelled and the focus of the regional study, relatively large coastal reaches were used for the 1-D coastal model (233 transects for the entire coastline of the CVRD). A simplified approach for riverine modelling was also followed with relatively old LiDAR information (2012, adjusted locally to update the elevations along the Canterbury floodwall), in which flood protection structures were included in the model Digital Elevation Model (DEM) based on LiDAR data only (not surveyed or modelled as structures). For the riverine modelling, design flows for input into the riverine model were based on the 2013 regional flood frequency analysis (i.e., more recent hydrological data was not included) and climate change was considered with percent increases (i.e., not based on a detailed climate change study). More details about datasets, methods, and limitations of the flood hazard data can be found in Kerr Wood Leidal Associates Ltd. (2021).

2.1.4 Hazard Confidence Ratings

For each of the delineated hazards, confidence ratings were assigned. Confidence ratings provide an indication of the robustness of a risk assessment (AIDR, 2020). This is essential, as risk assessment outputs inform decisions, and decision makers should be aware of potential uncertainties in the underlying data. Five confidence ratings, simplified from the Australian Institute for Disaster Resilience guidelines (AIDR, 2020) and Ebbwater Consulting Inc. (2022), were considered (Table 2-2).

Table 2-2: Confidence ratings for hazard, simplified from AIDR (2020) and (Ebbwater Consulting Inc., 2022).

Hazard Confidence Rating	Descriptor	Supporting evidence
Very high	Almost no uncertainty	Quantitative modelling/analysis of highest quality and length of data relating directly to the affected community and assessed hazard scenario, or recent historical event of similar magnitude in community of interest.
High	Some uncertainty	Quantitative modelling/analysis with sufficient quality and length of data directly relevant to assessed hazard scenario, or recent historical event of similar magnitude in a directly comparable community.
Moderate	Substantial uncertainty	Quantitative modelling/analysis with reasonable extrapolation of data required to derive results of direct relevance to the event being assessed, or historical event of similar magnitude in comparable community.
Low	Major uncertainty	Quantitative modelling and analysis with extensive extrapolation of data required to derive results of relevance to the event being assessed, or some comparable historical events through anecdotal information.
Very low	Fundamental uncertainty	No historical events or quantitative modelled results to support the levels.

The CVRD Coastal Flood Mapping project modelled the Puntledge, Tsolum, and Courtenay Rivers and the coastal area quantitatively *with sufficient quality and length of data*. However, due to the regional approach used for the coastal area, and the rest of the limitations listed in Section 2.1.3, each of the flood hazard layers was assigned a confidence rating of high.

2.2 Consequence Methods

As a first step in this risk assessment, we sourced data from the City, from public provincial and national datasets, as well as from other federal organizations. We then conducted a systematic data gap analysis, and filled key data gaps, such as cooperating with the City to collect strata unit maps and refine our building information. The datasets were then processed and reviewed both internally and externally, using the local knowledge of City staff to ground-truth our spatial information.

There are a lot of challenges when it comes to assembling datasets for a local study. Regional, provincial, or even national scale datasets are often not designed to provide information for a building-level analysis and might present discrepancies (that in contrast would not be as substantial in a regional scale study, compared to local scale). To mitigate this, we refined parts of the datasets manually with guidance from City staff. However, even though efforts were made to increase the accuracy of the datasets at the scale of this project, assumptions were still needed to be made to be able to produce results for all different receptors in a consistent manner.

The next subsections summarize the wide range of consequence data per receptor, present the assumptions made for each dataset when applicable, and describe the confidence ratings for each of the receptors.

2.2.1 Receptors and Data Proxies

Consequences to floods can vary widely – from direct/tangible consequences to indirect/intangible consequences (see main report, Section 2). They can also affect different assets valued by society including economy, culture, and environment. To support flood risk assessments, it is helpful to categorize and organize these impacts. There are a number of taxonomies (schemes of classification) that are used in the field of Disaster Risk Reduction (DRR) (e.g., UN Indicators and Terminology relating to DRR, Societal impacts within the Sendai Framework (UNDRR, 2015), consequence types within Canada's National Risk Profile (Public Safety Canada, 2023) as well as other national and international resources (UNDRR 2015, 2016, 2017; BC MECCS 2019; AIDR, 2020). Based on these documents, the following six receptors can guide risk assessments, and are aimed at providing a holistic view of potential consequences (Table 2-3). Note that these are not listed in order of importance.

Table 2-3: Description of receptors.

Affected People	People are affected in a range of ways by floods. This may include people who are injured or suffer other health effects (e.g., trauma or stress), are evacuated or displaced, or suffer due to compromised livelihoods (e.g., their uninsured house is damaged, or they lose their job).
Mortality	This receptor describes the estimated number of deaths and missing persons due to a flood.
Critical Infrastructure	Flood can impact many types of infrastructure that are regarded as necessary for communities to function. This can include transportation infrastructure such as ferry docks and highways, as well as health services, emergency response (police, fire, ambulance), and government facilities. Utilities, such as power systems, water and wastewater, and telecommunications, are also critical.
Economics	Flooding can cause potential economic losses through property and equipment damage and other far-reaching consequences. This includes repairs to public and private infrastructure, and losses due to reduced revenues following a flood.
Culture	The cultural life of a community may experience various impacts due to a flood. This includes both Indigenous and non-Indigenous cultural sites, historic uses, as well as recreational spaces, trails, and sacred areas. It can also include community centres, schools, and other important gathering places.
Environment	Flooding is an important component of many ecosystems and is a naturally occurring process. Green spaces can provide positive benefits by absorbing flood waters. On the other hand, floods may lead to the overflow or discharge of contamination sources into the environment, or cause damage to environmentally sensitive areas. Contamination may include sewage and fuel spills from flooded septic systems and storage buildings.

In a risk assessment, where direct measures are not possible to characterize a receptor, proxies can be used. A proxy is a measurable quantity (e.g., number of affected people, or buildings in a floodplain) that is a reasonable representation of a receptor, based on a set of assumptions. The datasets used to measure each of the receptors are discussed in the sections below.

2.2.1.1 Affected People

The number of affected people in the City was estimated based on census data, under the assumption that people are most affected where they live (Table 2-4). However, the smallest units at which census data is provided are Dissemination Areas (DAs). While DAs are relatively small for urban centres (e.g., several blocks), assumptions are still required to produce detailed population estimates per building. This makes the use of census data for detailed risk assessments challenging, even though it still is the most detailed information available for many areas.

For this project, the number of affected people was mapped using the most recent Canadian Census data *(Statistics Canada, 2021),* considering population numbers based on dissemination area in combination with residential building footprints (identified based on BCA data (BCA, 2022). To estimate the number of affected people, an additional analysis was performed to avoid using a one-to-one relationship between buildings footprints, units (for townhouses or apartments), and land parcels. The challenge here was that several parcels may overlay at one location (e.g., if one parcel covers a townhouse complex), and therefore, several BCA entries exist for property values and other information; similar issues arise if multiple apartment units are within one building (one building footprint). The details of processing of land parcel and BCA data are described in Chapter 3.

In the next step, 2021 Census was used to estimate the population, based on the estimated numbers of units linked to each building footprint. The smallest available neighborhood block's total population was determined using the Census DA, as mentioned above. Then, we calculated the total number of units contained within each DA to derive an average population per unit, and then finally multiplied this number by the quantity of units that each building footprint possessed. In doing so, we were able to formulate an estimation of the population for each of the building footprints.

Table 2-4: Dataset details for the affected people receptor.

1. Affected People Receptor			
Proxy	**Dataset**	**Assumption**	**Limitations**
Number of people in hazard extent	Building footprints from the City; number of people assigned to each residential building (adjusted for unit numbers) based on the 2021 census (Statistics Canada, 2021) and (BCA, 2022).	People are most affected where they live, and not in their work environment or recreation.	Assumption of an even distribution of people per unit. Census data dissemination areas size. Uncertainty about the completeness of building footprints. Uncertainty associated with the available BCA information and related parcel fabric. BCA information was not detailed enough to allow for direct and accurate identification of residential buildings. When relevant information was available, multiple apartment units were assigned to one building footprint. This more detailed approach was performed only for buildings within the floodplain which might lead to an overestimation of affected people (as more apartment blocks might exist outside of the floodplain). Does not include indirect impacts on people outside the hazard extent, nor considers seasonally changing populations or visitors.

2.2.1.1.1 Social Vulnerability (Intersectional Disadvantage)

An important consideration is the intersectional disadvantage (or social vulnerability) of people, which will affect how well they can respond to a flood, and what the impacts may be.

Intersectional disadvantage: The intersection of social categorizations of persons or classes of persons, including Indigenous identity, race, economic status, sex, sexual orientation, gender identity and expression, age and ability, in ways that may result in overlapping systems of discrimination or disadvantage or disproportionate adverse effects (Province of BC, 2023).

Research for social vulnerability explores how some individuals are more susceptible than others to exposures (differential susceptibilities) and capacities of populations affected by disasters (Tate and Emrich, 2021). However, the research is complex, has limitations, and is still evolving. Importantly, addressing vulnerability means addressing a wider range of issues related to equity, diversity, and inclusion.

Intersectional disadvantages refers to the extent of which certain individuals or societal groups are more prone to harm from exposure to hazards, directly affecting their ability to prepare for, respond to, and recover from disasters and crises. It encompasses a variety of factors including socioeconomic status, demographic characteristics, health, and disability status, as well as many other social factors. Taking into account social vulnerability when dealing with hazards is important as it can lead to less human distress and a decrease in the financial costs associated with post-disaster public assistance and social services (Flanagan et al., 2011).

For this project, to evaluate social vulnerability, the framework from the Land and Minerals Sector of Natural Resources Canada (NRCan), based on the 2016 census data, was adopted. The regional Social Vulnerability Index (SVI) assessment system utilizes four thematic categories, each represented by a specific set of indicators (Journeay et al., 2022)[5]:

Social Capital: It includes measures related to family structure, migration, immigration, and workplace relationships. These factors indicate the level of interconnectedness within a community and its mutual dependency during challenging times.

Individual Autonomy: This category incorporates indicators such as the level of formal education, caregiving responsibilities, language barriers, Indigenous identity, and reliance on public transit. These elements assist in evaluating the capability of individuals and groups to make independent decisions and influence risk management strategies.

Housing Conditions: This category comprises of indicators related to population density, housing suitability, adherence to building safety regulations, and the ability for maintenance and upkeep of residences. These elements aid in determining whether individuals are likely to remain in their homes or seek emergency services during a disaster and estimate the duration required to restore standard services.

Financial Agency: This dimension encompasses measures of income stability and job security, which reflect the financial resilience of individuals and groups during a disaster. These indicators evaluate economic stability and overall recovery prospects following a catastrophe.

To interpret model results more easily, the values of the above indicators are converted from absolute minimum-maximum values to relative vulnerability threshold scores. These are determined by

[5] https://github.com/OpenDRR/national-human-settlement

comparing measured values at a location against the average values for a specific settlement type. A score of +1 is given when an indicator exceeds the mean value plus one standard deviation, while those that fall below this threshold are given a score of 0.

This process of evaluating threshold scores for all indicators within each settlement type results in four distinct measures of relative vulnerability, which can then be consolidated into a composite social vulnerability index (SVI). The SVI threshold scores record the number of instances where vulnerability measures exceed the reference threshold values for the same settlement type.

Vulnerability degrees are classified into "low", "moderate", "considerable", "high", and "extreme" by using the Jenks classification (Journeay et al. 2022), a data clustering method that groups scores based on natural breaks. Given that there are five indicators within each of the four thematic dimensions, vulnerability threshold scores can vary from 0 to 5 for each model component, with the maximum value for the composite index score being 20.

The indicators were each mapped for the City (based on the 2016 Census DAs), along with the SVI which encompasses all the four indicators together. Note that the above framework includes characteristics that are not all targeted to flood hazards (e.g., Housing Conditions take into account the date of the construction of the building to evaluate if it follows seismic regulations). For that reason, the housing conditions index was not mapped, but is, however, included in the composite index, assuming that overall, newer buildings may be more flood resilient than older buildings.

Social vulnerability maps, for the combined SVI as well as the four separate categories are presented below in Figure 2-1 to Figure 2-5:

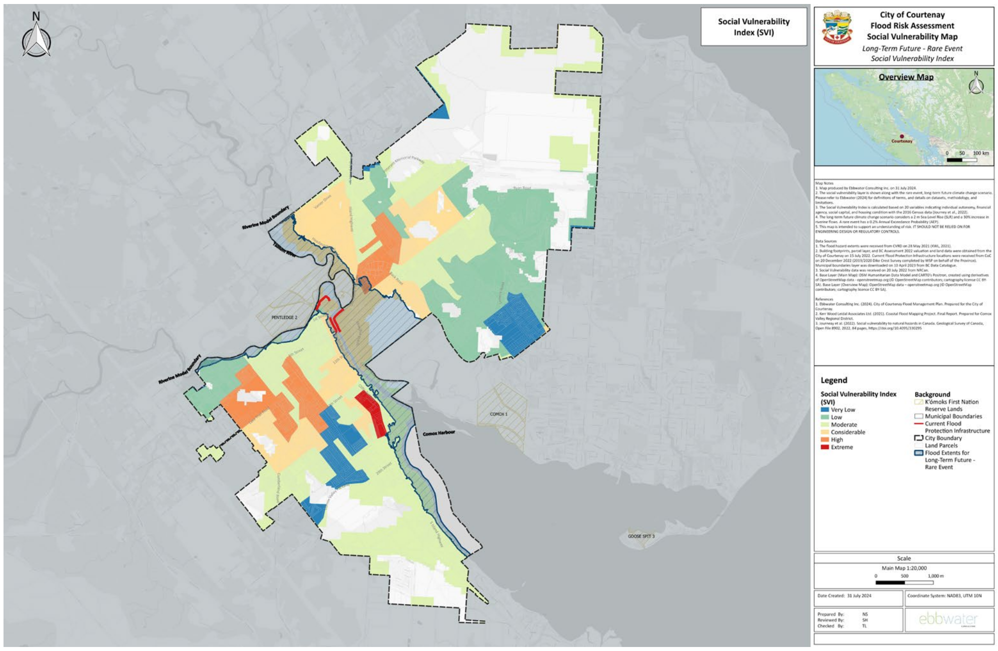

Figure 2-1: Social Vulnerability for the City of Courtenay, based on the Canada Social Vulnerability Model from NRCan (Journeay et al., 2022). The mapped Social Vulnerability Index (SVI) is the sum of four indicator categories, and flood extents of the long-term future rare (0.2% AEP) scenario are shown.

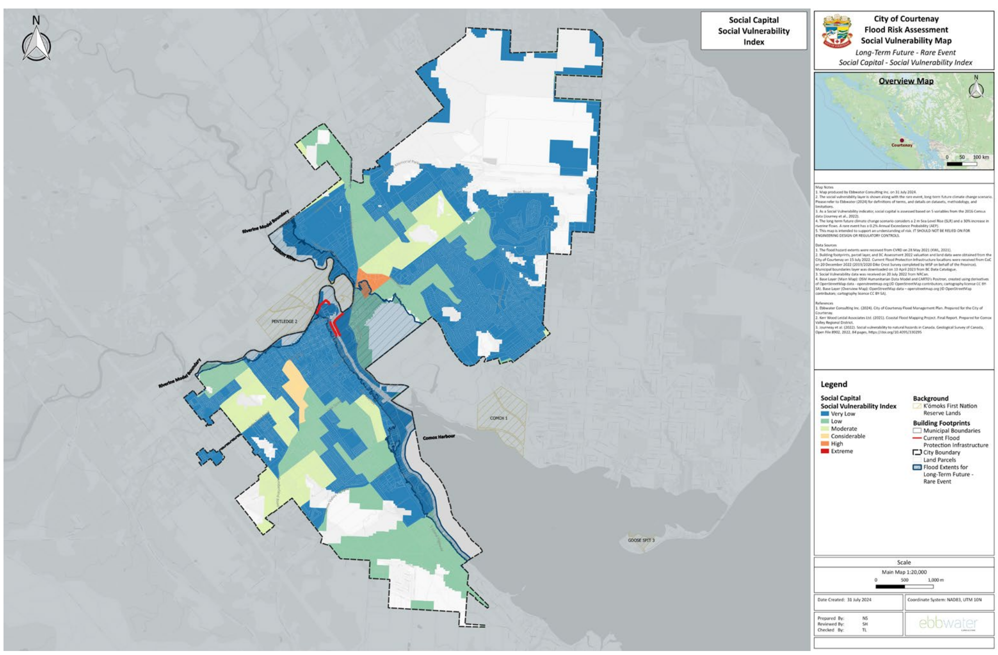

Figure 2-2: Social Capital index for the City of Courtenay, based on Journeay et al., (2022). Flood extents of the long-term future rare (0.2% AEP) scenario are shown.

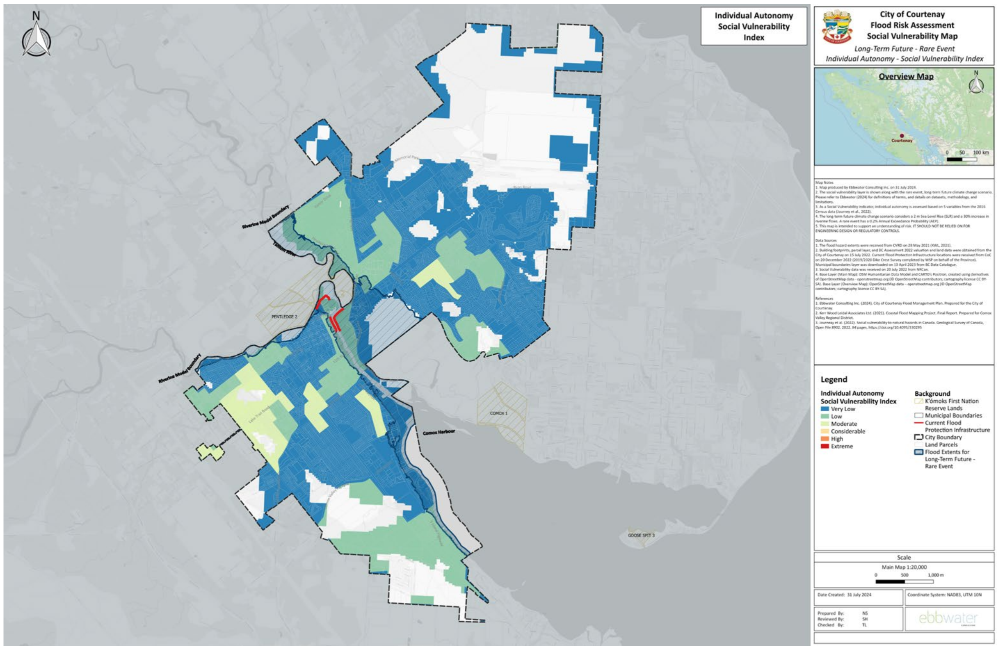

Figure 2-3: Individual Autonomy index for the City of Courtenay, based on Journeay et al., (2022). Flood extents of the long-term future rare (0.2% AEP) scenario are shown.

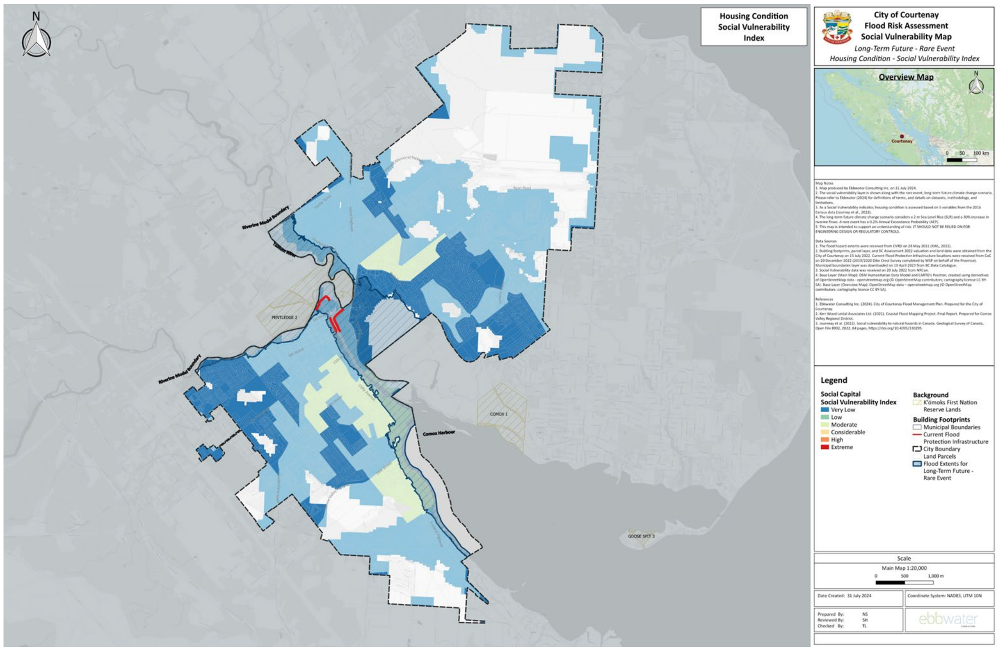

Figure 2-4: Housing index for the City of Courtenay, based on Journeay et al., (2022). Flood extents of the long-term future rare (0.2% AEP) scenario are shown.

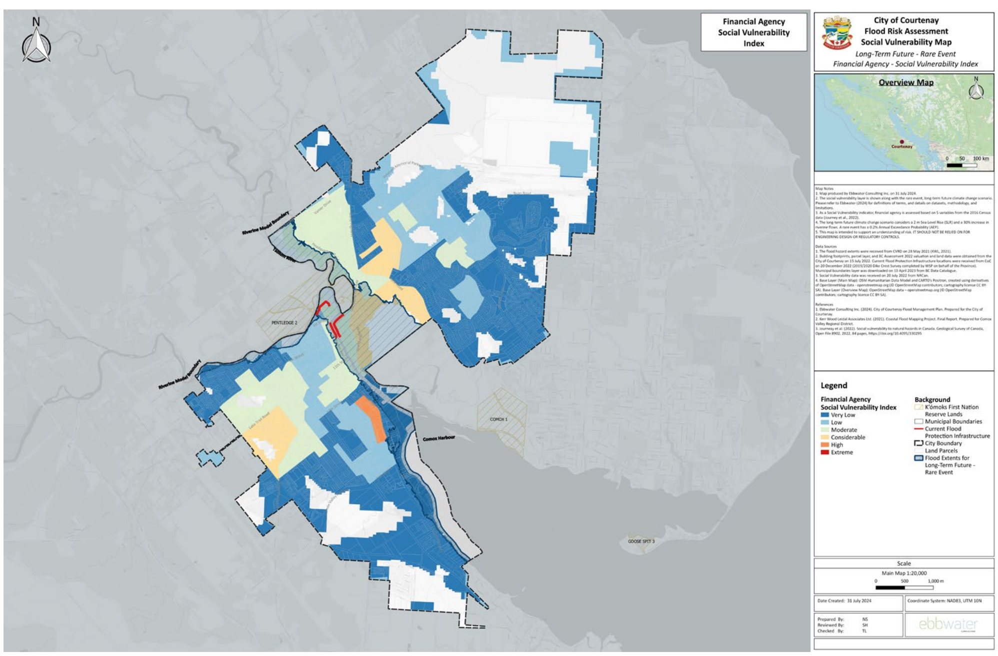

Figure 2-5: Financial Agency index for the City of Courtenay, based on Journeay et al., (2022). Flood extents of the long-term future rare (0.2% AEP) scenario are shown.

2.2.1.2 Mortality

Mortality describes the number of deaths and missing persons due to a natural hazard event. Mortality from riverine and coastal flooding is relatively low in Canada (Public Safety Canada, 2022).

Mortality was estimated as a fraction of the total number of affected people, based on flood events recorded in the Canadian Disaster Database (Public Safety Canada, 2022), including those events where dike breaching had led to flooding (Table 2-5). Although mortality due to flooding is generally low in Canada, a dike breach can potentially have a higher mortality than other floods, due to typically short warning time and high flow velocity, so we assumed this estimate as a worst-case scenario. Note that mortality estimates do not consider individual site and event characteristics, which differ widely, nor warning time and evacuation procedures and are a high-level estimate only.

Also note that as mortality was estimated as a percentage of affected people, and the spatial distribution throughout the City is therefore the same for this simplified approach as for the affected people consequence map, as well as the very low mortality estimates, no separate mortality consequence map was developed.

Table 2-5: Dataset details for the mortality receptor.

2. Mortality Receptor			
Proxy	**Dataset**	**Assumption**	**Limitations**
Associated fraction of number of affected people	Mortality fraction of approx. 0.01% (Public Safety Canada, 2022)	Fatalities can be estimated based on observed events (flooding due to structure failure).	Does not consider individual site and event characteristics, which differ widely. High-level estimate only. Depends on affected people estimate, i.e., has similar limitations. Future studies could consider warning, evacuation, and social vulnerability factors (e.g., demographics, resident versus tourist, etc.) that could affect mortality.

2.2.1.3 Economy

Economic damages from flooding should ideally consider both the direct and tangible financial losses associated with a flood event alongside wider impacts to the economy (e.g., regional business success). Methods to calculate the latter are complex and still novel, and therefore, given available data and resources, this project focussed on two proxy measures for the overall economy – losses associated with building and land damages, as well as losses associated with agricultural.

Building and Land Value

This receptor represents potential financial loss resulting from a natural hazard. For this study, the total building value (of all buildings in the flood hazard extent) was used as one proxy for economic impacts (Table 2-6). It was assumed that when water recedes after a flood, most of the damage will have occurred to the building infrastructure, and not to the land itself.

2022 BC Assessment data were obtained from the City for the project area (BCA, 2022) and were associated with the building footprints also acquired from the City, based on the methodology described in Chapter 3. This assessment data provides a snapshot of the 'official' building and land value, it may not reflect actual values as reflected in the local real estate market.

The building values from each building footprint intersecting with the hazard extent were summed up to calculate the total exposed value. For each hazard extent, the total property values (i.e., building value plus land value) were also reported, as the total property value can serve as a cost estimate for land acquisition if managed retreat is considered for risk reduction.

We further did substantial investigations to determine building vulnerabilities and estimate potential damages (in contrast to total building value, as described above). However, we encountered many challenges, including gathering input data (noting though that the City went through substantial efforts to provide main floor elevations for buildings, but other needed information such as building categories was challenging to obtain and determine), finding damage curve functions (e.g., via CanFlood[6], a toolbox which was under refinement), and further challenges (e.g., it can be difficult to estimate flood depth when a building is built on a slope), and eventually had to abandoned these efforts due to scope and budget limitations.

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[6] Natural Resources Canada: CanFlood https://github.com/NRCan/CanFlood

Agriculture

Economic loss can also occur from damage to agricultural land. As a proxy to agricultural impacts, we estimated the area of agricultural land within the City. We also provided a detailed listing of all crop types, and other land cover, within the various hazard extent (provided in spreadsheet format as attachment to this appendix).

This analysis was based on the Annual Crop Inventory (ACI) 2021 from Agriculture and Agri-Foods Canada (AAFC) (Agriculture and Agri-Foods Canada, 2021). This dataset is developed based on satellite observations from multiple sensors during key crop phenological stages (reproduction, seed development and senescence), and trained and validated using provincial crop insurance information and collected field information (AAFC, 2021). The resolution of the data is 30 m, and as it is developed as a Canada-wide dataset, there are some uncertainties when looking at the local scale.

Note that for consequence mapping, the extents of the agricultural land reserve dataset were shown instead of the ACI dataset, as it is a concept that the public is more familiar with, and the ACI may also have uncertainties at the local scale (given that it is a national dataset). The ACI however shows areas actually cultivated with crops, in contrast to the ALR extents, where not all land may be used for agricultural products. Therefore, for the risk assessment, the ACI was used.

Table 2-6: Dataset details for the economy receptor.

3. Economy **Proxy**	**Dataset**	**Assumption**	**Limitations**
Building value in flood hazard extent	2022 BC Assessment Authority (BCA) data (BCA, 2022) Building footprints (City, 2022)	Damage to entire building	Does not consider other potential direct and indirect economic losses (business interruptions, emergency response costs, reconstruction costs, etc.). Uncertainty associated with the available building footprints, BCA information and related parcel fabric. Uncertainty related to BCA information on unit numbers, etc.
Agricultural Area in flood hazard extent	Annual Crop Inventory 2021 (AAFC, 2021) Agricultural Land Reserve layer (BC Data Catalogue; Province of British Columbia, 2022)	Damage to agricultural crops	No economic data attributed. Canada-wide layer obtained from remote sensing – there are uncertainties at the local scale. Shows land designated for agricultural use, but not actual extents of crop cultivation.

Further economic consequences such as business interruptions, emergency response costs, reconstruction costs, and other indirect economic losses could not be assessed for this risk assessment but might be substantial. However, these economic consequences were assessed qualitatively and discussed in the main report for different local areas.

2.2.1.4 Environment

While riverine and coastal floods are important components of many ecosystems and are naturally occurring processes (which are in some cases worsened through anthropogenic land cover management), the contamination of flood waters by anthropogenic contamination sources can be detrimental, if these contaminated waters affect ecologically sensitive areas.

Contamination Sources

Contamination sources are considered present for operations where fuel, chemicals or other toxic, persistent substances may be stored in large amounts. Contamination data were obtained from City of Courtenay and included potential contamination sources that can be summarized as follows: auto dealerships, repair shops, body shops, and gas/diesel bulk plants and outlets (former and/or present) (Table 2-7)[7]. The dataset resulted in 126 potential sources of contamination for the entire City of Courtenay extents.

Sensitive Ecosystems

We also assessed the area of sensitive ecosystems within the hazard extents. The assessed datasets include the distribution of Species and Ecosystems at Risk, Conservation Areas, and Groundwater Wells (Table 2-7). The above data were obtained from the BC Data Catalogue (Province of British Columbia, 2022). Fish habitat locations were received from the City. Also, local parks were added, as received from the City, along with Local and Regional Greenspaces downloaded from the BC Data Catalogue (Province of British Columbia, 2022). Note that parks and greenspaces are included here as a proxy (in the absence of more detailed sensitive ecosystem information). While flooding less sensitive green spaces might be an effective flood mitigation strategy, these areas might also contain sensitive ecosystems that are vulnerable to anthropogenic contamination sources. Further,

[7] The full list based on the dataset (provided by the City of Courtenay includes: Auto Dealers, Repair Shops, Body Shops, or Potential Sites, Former and Present Gasoline/Diesel Bulk Plants, Former Gas/Diesel Outlets AND Auto Dealers, Repair Shops, Body Shops, or Potential Sites,Former Gasoline/Diesel Outlets,Multiple Contamination Causes, Present Gas/Diesel Outlets AND Former/Present Gasoline/Diesel Bulk Plants, Present Gasoline/Diesel Outlets.
Multiple Contamination Causes: Former Site of Courtenay Home Service & Home Oil Bulk Plant. Present Site of Esso keylock and Former Site of BA Service Station, Royalite Gas Bulk Plant & Columbia Fuel Key lock etc.

downstream consequences of contamination sources could also lead to more widespread environmental consequences, and other indirect and intangible consequences.

Table 2-7: Dataset details for the environment receptor.

5. Environment **Proxy**	**Dataset**	**Assumption**	**Limitations**
Location of Contamination Sources in hazard extent	Contaminated sites (City of Courtenay, received on 15 July 2022)	Damage leads to contamination of flood waters, with negative consequences for sensitive ecosystems within various hazard extents.	Not all local contamination sources were captured in the datasets. No differentiation between different types *of* contamination sources.
Area of Sensitive Ecosystems in hazard extent	BC Data Catalogue (Province of British Columbia, 2022): - Species and Ecosystems at Risk Distribution - Conservation Lands - Groundwater Wells - Local and regional greenspaces City of Courtenay data package (received on 15 July 2022): - Fish habitat locations (Lamprey eel) - Parks	Flooding has negative effects on ecosystems due to contamination of floodwaters.	Not all sensitive ecosystems might be captured in provincial database, especially species at risk distribution might be wider than indicated in spatial dataset. Downstream consequences of contaminated flood waters were not considered. The severities of different sources of contamination were not distinguished.

2.2.1.5 Culture & Recreation

The consequences of flood to the culture of a community can be widespread and include tangible consequences such as loss of cultural sites, but also more intangible aspects such as loss of education, changes to the culture of a community, and more. As proxy for cultural consequences, the number of cultural sites within the various hazard extents was assessed (Table 2-8). Cultural sites were selected that are likely to have high social value to a community and for which there is consistent and comprehensive datasets. This includes heritage sites, Indigenous and non-Indigenous archaeological sites, indoor and outdoor recreational sites, community centres, care centres, religious centres, and educational buildings. Finally, as a large part of the local culture depends on access to the outdoors, in addition to aforementioned sites, trails and greenways obtained from the City of Courtenay were also taken into account. These cultural sites can obviously only capture part of what forms the culture of a community, but they can provide an indication of potential cultural consequences of floods.

The datasets were based on the BC Data Catalogue (Province of British Columbia, 2022), City of Courtenay data package, and an Archaeological and Heritage site dataset obtained from the Archaeology Branch at the Ministry of Forests, Lands and Natural Resource Operations Region & District *(MFLNRORD, 2022)*. Note that the various building locations in the datasets were associated with building footprints, received by the City of Courtenay. A Critical Facilities list was associated with map locations based on addresses. The City staff reviewed the related consequence maps, to support in the identification of most, if not all, local cultural sites within the floodplain. However, note that a major limitation to this project is that only limited engagement with the K'ómoks First Nation was possible, due to capacity limitations from the Nation.

Table 2-8: Dataset details for the culture receptor.

6. Culture Proxy	Dataset	Assumption	Limitations
Cultural sites in hazard extent	BC Data Catalogue (Province of British Columbia, 2020): - Civic Facilities (museums, community halls, recreation centres, pools, etc.) - Child Care - Education (schools K12, post-secondary) 2022 BC Assessment Authority (BCA) data (BCA, 2022). Archaeological and Heritage Sites (MFLNRORD, 2022): - Heritage Sites - Indigenous archaeological sites - Indigenous traditional use sites - Non-indigenous archaeological sites City of Courtenay data package (received on 15 July 2022): - Trails - Greenways - City Buildings	Cultural sites can indicate consequences to the culture of a community.	Proxies for cultural consequences cannot capture intangible consequences of cultural impacts. Not all local cultural sites may be captured/data uncertainties/inconsistencies exist. Building locations (point files) in the datasets were associated with the nearest building footprints, an assumption which might not always be accurate, depending on data quality. Cultural Facilities (sublist of Critical Facilities) list was associated with map locations on google maps based on street addresses. This method can introduce uncertainty to the spatial data. Archaeological dataset may not be complete. Many more cultural impacts likely exist which are not captured.

6. Culture Proxy	Dataset	Assumption	Limitations
	- Critical Facilities List (extracted relevant data for culture)		

2.2.1.6 Critical Infrastructure

Critical Infrastructure Facilities

Critical infrastructure facilities include emergency response and first responder facilities (i.e., fire hall, police, and ambulance stations), hospitals, local government offices (which typically support emergency response efforts), as well as transportation hubs (air parks), and food banks (Table 2-9). To identify the location of such facilities, spatial data from the BC Data Catalogue were used (Province of British Columbia, 2022). Additionally, critical infrastructure facilities were identified using a critical facilities file received from the City of Courtenay. The various building locations in the list were associated with building footprints, based on the provided addresses.

Disruption of Basic Services

Disruption of basic and critical services, such as electricity, telecommunication, and road and train access can also lead to wide-spread cascading effects on a society. Using data from the Integrated Cadastral Information (ICI) Society (ICI, 2022), the number of overhead electrical distribution poles and transmission structures in the hazard extent was determined (Table 2-9). No electrical substations were identified within the floodplain. Note that wooden poles are susceptible to damage during long-duration flood events, and transmission structures, depending on their design, might be susceptible to failure due to saturated ground in their foundations. No damage to underground structures was assumed. The number of telecommunication facilities in the various hazard extents was also determined, based on ICI data. The length of roads in the hazard extent was determined based on BC Data catalogue (Province of British Columbia, 2022) information. Arterial roads and highways were considered major roads. Note that there were no railway tracks in the project area.

The City staff reviewed the related consequence maps, to support in the identification of local critical infrastructure sites and infrastructure within the floodplain. However, due to the nature of the data, proxies for critical infrastructure consequences likely cannot capture the full complexity of its impacts.

Table 2-9: Dataset details for the critical infrastructure receptor.

4. Critical Infrastructure and Disruption of Basic Services			
Proxy	**Dataset**	**Assumption**	**Limitations**
Location of critical facilities in hazard extent	BC Data Catalogue (Province of British Columbia, 2022): - First Responders - Local Government Offices - Hospitals - Air Parks - Food Banks ICI Society Data (ICI, 2022): - BC Hydro Substations City of Courtenay data package (received on 15 July 2022): - Critical Facilities List (subset related to Critical Infrastructure)	Flood damage to critical facilities.	Some local critical facilities might not be captured. Building locations (point files) in the datasets were associated with the nearest building footprints, an assumption which might not always be accurate, depending on data quality. Critical Facilities list was associated with map locations on google maps based on addresses. This method can introduce uncertainty to the spatial data.
Location of line/point features of basic services in hazard extent	BC Data Catalogue (Province of British Columbia, 2022): - Railway Tracks ICI Society Data (ICI, 2022) - BC Hydro and Fortis distribution poles - BC Hydro and Fortis transmission structures - Telus and Shaw telecommunication facilities (pedestals) City of Courtenay data package (received on 15 July 2022): - Roads	Damage or interruption of use to roads and railways. Damage to overhead electrical poles (underground features assumed to not be affected).	Damage to overhead electrical poles might be limited due to flooding but is included for a conservative approach.

2.2.2 Consequence Confidence Ratings

Given the uncertainties in data proxies and in determining the consequences for many of the receptors, a consequence confidence rating (Table 2-10) was assigned for each receptor. The consequence confidence rating describes the data availability for each receptor, and how well the proxy data can capture the tangible and intangible consequences associated with the receptor (Table 2-11). The rating table was broadly based on (AIDR, 2020), but adjusted for the purposes of this project. Especially for culture and environment receptors, many intangible consequences exist, which cannot be quantified.

Table 2-10: Consequence confidence rating descriptions and criteria (based on (AIDR, 2020), adjusted).

Consequence Confidence Rating	Description	Criteria
5	Very High	Proxy data can well capture all tangible and intangible consequences for a receptor and is reliably available at local scale.
4	High	Proxy data can relatively well capture consequences for an receptor and is available at local scale.
3	Moderate	Proxy data can capture most consequences for a receptor. But while available at local scale, some data uncertainties/inconsistencies exist, or not all local assets may be captured.
2	Low	Proxy data can capture some consequences for a receptor, but some assets might be missing, or not all tangible/intangible consequences might be captured.
1	Very Low	Only limited data and methods exist, and proxy data can only capture a small part of the consequences of a receptor, or the method to determine the proxy data is very uncertain.

Table 2-11: Assigned consequence confidence ratings for each receptor and rationale for this project.

Receptor	Assigned Consequence Confidence Rating	Rationale
1. Affected People	Moderate	Dissemination area (i.e., local data) is available, which can capture primary consequences, but some uncertainties/ inconsistencies exist in the data.
2. Mortality	Low	Only a very uncertain method exists to estimate mortality.
3. Economy	High	A detailed local and up-to-date (BCA 2022) dataset exists, which captures the primary economic consequences, albeit not all direct and indirect consequences.
4. Environment	Low	While available contamination sources data is relatively reliable, not all contamination sources are included. Further, many more tangible and intangible consequences may exist.
5. Culture	Low	While provincial and local cultural sites datasets exist, some uncertainties/ inconsistencies exist in the data, e.g., not all Indigenous archaeological sites may be captured. Further, this proxy can only capture a small part of the tangible/intangible consequences to the cultural of a community.
6. Critical Infrastructure	Moderate	Relatively reliable data exists, which can indicate the primary critical infrastructure consequences. However, the cascading consequences may not be captured.

2.2.3 Consequence Calculations

For this risk assessment, mostly, exposure (i.e., what is within the flood hazard extent of a specific scenario) was used as a proxy for consequences. This involved overlaying the quantitative spatial receptor data and the flood hazard extents, and calculating total numbers (e.g., of affected people) for each combination of receptors and hazard scenarios.

2.3 Risk Methods

While consequence maps provide key spatial information for selected scenarios, they do not capture the full range of potential flood events nor factor in the likelihood of those events. As a result, while they can give a useful snapshot of potential risk in specific scenarios, it may not provide a comprehensive understanding of the full range of risk. We therefore also developed exceedance probability curves ('risk curves'), which relate the hazard likelihood (i.e., AEP) with an associated consequence, such as the number of affected people (Figure 2-6). We developed risk curves for each receptor (for key data proxies) for each of the four time periods, by linearly interpolating between the five likelihoods for each time period. Next, we calculated the average annual loss (AAL) (sometimes referred also as expected annual damage (EAD)), which is the "long-term expected loss on an annualized basis, averaged over time" (UNDRR, 2017). The AAL describes the average expected loss over a long period, which takes into account frequent events with potentially little loss, as well as infrequent events with potentially larger losses. In terms of dollar values, the AAL could represent the "amounts of funds that need to be put aside annually in order to cumulatively cover the average disaster loss over time" (UNDRR, 2017). The AAL refers to the total risk (or full statistical risk), as a product of likelihood and consequence for each possible likelihood, and is calculated as the total area under the risk curves.

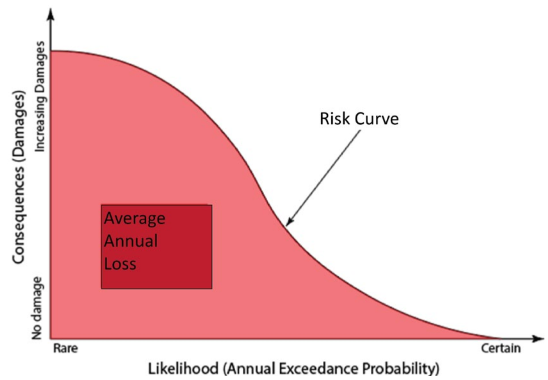

Figure 2-6: Example of a risk curve (exceedance probability curve), and AAL (average annual loss) calculated as area under the curve.

2.4 Software

For this analysis, we used the open-source coding software R (R Core Team, 2022), and specifically, incorporated functions from the following R packages: 'sp' (Bivand et al., 2013; Pebesma & Bivand, 2005), 'rgdal' (Roger Bivand, 2022), 'maptools' (Lewin-Koh, 2021), 'raster' (Hijmans, 2021), 'rgeos' (Rundel, 2021), and 'sf' (Pebesma, 2018). For mapping, we used the open-source GIS software QGIS(QGIS.org, 2023).

2.5 Challenges & Limitations

Given the information, timing, and resources available to complete this project, there were challenges and limitations to the work completed.

1. **Limited engagement with K'ómoks First Nation** was possible, due to capacity limitations from the Nation.
2. **Integration of results.** Substantial work was required to process and interpret quantitative data. While the results are presented at relatively detailed resolutions in consequence maps, some uncertainties at the building-level remain.
3. **Hazard data uncertainty.** The hazard assessment approaches for coastal and riverine flooding were detailed, but there is an inherent uncertainty tied to any hydraulic modelling process, especially when using a regional model for a local study. Further, processes such as outburst floods from sudden breach of natural (or man-made) flood structures (e.g., dike breach) were not considered. In terms of the riverine model, for the majority of the flood mapping for the Courtenay River, the topography in the model is based on the 2013 LiDAR data used in the Courtenay IFMS project (McElhanney, 2013), and it only includes the adjustment of the topography to represent the existing floodwall surrounding the Canterbury Place development. Finally, the riverine and coastal events were considered to have the same AEPs for each scenario, an assumption which is not always accurate as a combination of different storm events can potentially be more extreme than the one used for modelling, i.e., a joint probability approach was not used. Further details on model limitations can found in Section 2.1.3, as well as in KWL (2013), McElhanney (2013), and KWL (2021J).
4. **Consequence data uncertainty.** Due to the quality of some of the datasets used as inputs, the results are inherently uncertain. There are many uncertainties related to available consequence data; the limitations of the consequence receptors and their data proxies were discussed in Section 2.2.1. These include uncertainties related to the method of population distribution across the City of Courtenay and issues related to BCA information. For economy receptor consequences, we did not consider *other potential direct and indirect economic losses*. For environment, culture, and critical infrastructure receptor consequences, uncertainties/ inconsistencies exist in the data, and not all sites or contamination sources were captured in the datasets. To acknowledge the above limitations, a method was applied to develop confidence ratings (Section 0), which were subsequently assigned to each receptor.
5. **Lack of prescriptive methods.** There is currently little guidance within Canada and BC to complete natural hazard risk assessments. The project team relied on international best practice and the completion of recent projects having similarities in quantitative data gathering and analysis.
6. **Vulnerability was not assessed quantitatively.** Exposure was used primarily as a proxy for consequence in the risk assessment, and vulnerability was presented through a qualitative

assessment based on the SVI datasets. Vulnerabilities were also further discussed in engagement activities and are detailed in local area sections in the main report.

Apart from these limitations, the risk assessment was conducted in a consistent, robust, and scientifically reproducible manner, considering a holistic set of consequence receptors.

3 BC Assessment and Parcel Data Processing for Consequence Data

3.1 Introduction

As discussed in the chapter above regarding consequence data, BCA datasets (typically linked spatially to land parcel data) provide important input for many quantitative proxies to describe consequence receptors. This section provides more background on the BCA and land parcel data processing that was conducted for this project.

Property value (including building and land value) is a critical component for a comprehensive and detailed flood risk assessment. In British Columbia, information such as building values and land use is usually assessed from BC Assessment information. Using the BCA datasets is generally sufficient in regional studies. However, more processing is needed for detailed, local projects, such as the City of Courtenay flood risk assessment, especially where there are apartment towers, townhouses, and manufactured home parks.

Additionally, building footprints have been used as a critical component to estimate population distribution. Some high-level analysis (e.g., Building Population Layer Canada [8]) assume that population density is uniform across all the buildings within a census unit such as a dissemination area. However, it is unrealistic to assume that townhouses and apartment towers will have the same population density as single-family houses. Not addressing the population difference among different types of buildings will lead to substantial bias, especially in local-scale flood risk assessment projects.

In this chapter, we first describe the problem, then our method to process the data, and finally limitations of this method.

3.2 Problem Description

It is necessary to combine two types of data (land parcels and building footprints) to set up a building dataset:

1. Land parcels: Land parcels are basic spatial units used by BC Assessment. They are linked to information such as building values, land values, total property values, land use designations,

[8] https://github.com/nexeons/buildingpopulationlayer/blob/main/BPL-Canada-beta.py

sometimes unit number, and more. However, land parcels are usually much larger than the actual building footprints within the parcels and therefore are not suitable for building-oriented analyses and flood risk assessments (FRAs).

2. Building footprints: Building footprints can be derived from large-scale projects (e.g., Microsoft Canadian Building Footprints[9]) or local studies (e.g., City of Courtenay Building Footprints[10]). The footprint extent is very similar to the actual buildings, but usually there is no additional information (such as property values) attached to spatial building footprint datasets.

The integration of land parcel and building footprint datasets can therefore provide comprehensive building datasets where detailed land and building information can be transferred into building footprints with better spatial resolution. Usually, a land parcel will only contain one building (e.g., single-family homes). When there is a one-to-one relationship between buildings and land parcels, it is straightforward to integrate land parcel information and building footprint extent (Figure 3-1).

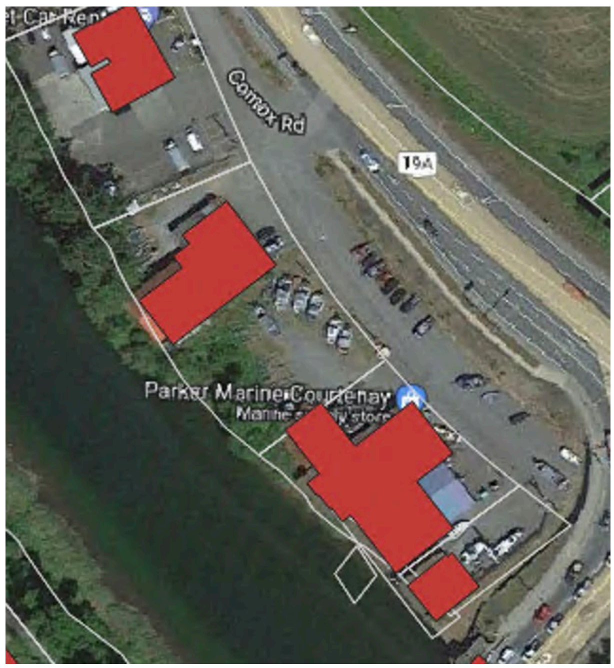

Figure 3-1: An example showing there are up to one building in a land parcel.

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[9] https://github.com/microsoft/CanadianBuildingFootprints

[10] https://data-courtenay.opendata.arcgis.com/items/9001ac2e150d40b0b380836a78ba0818

There are also some parcels without buildings (i.e., no buildings have been built in these parcels). But empty parcels are not common in the City, and usually do not affect FRAs because they do not contain building values.

However, there are some exceptions where the one-to-one relationship between land parcels and footprints does not apply. Some examples are discussed below:

1. In Figure 3-2, there is only one building, which is a large apartment tower with 31 units. However, the land parcels are 31 overlapping parcels with the same extent (as 31 separate entries with distinct parcel IDs exist within the BCA data, therefore, when linking the BCA data to spatial land parcels, 31 overlapping parcel polygons are generated). Without any processing, only the information from one unit will be linked to the building footprint, which substantially underestimates the building and land value associated with the building.

Figure 3-2: An example showing one apartment building footprint sits on 31 overlapping parcels.

2. Figure 3-3 shows an example where multiple building footprints will be on multiple overlapping parcels. This is more complicated than the previous example (Figure 3-2), as specific land parcels should be linked to specific buildings.

Figure 3-3: An example showing 9 townhouse footprints on 54 overlapping parcels.

3. Figure 3-4 shows that in a manufactured home park, 27 buildings can be found in 4 land parcels. Additionally, manufactured home areas in BC Assessment are divided into manufactured home parks with both land and building values and manufactured home units with only building values. Hence, it is necessary to combine the values of manufactured home units and manufactured home parks.

Figure 3-4: An example showing 27 building footprints are detected in a manufactured home park consisting of 4 land parcels.

Given the examples, it is critical to process the building and land parcel datasets rather than simply combining the information together under the assumption that the one-to-one relationship between buildings and parcels always applies. In Section 3.3, we provide several methods to address the aforementioned issues related to property values.

Additionally, by applying the same methodology, we can substantially improve the understanding of population distribution, compared to the rudimentary understanding based on the one-to-one relationship between buildings and parcels.

3.3 Processing Methods: Economy

In this section, we briefly describe how we corrected building values for the buildings where the one-to-one building-parcel relationship did not apply. Two main methods were used in this project, depending on whether strata unit maps were available in the area.

3.3.1 With Strata Unit Maps

Some strata unit maps were obtained from City of Courtenay. The strata unit maps can locate units to their corresponding building footprints. Therefore, it is possible to assign building values to certain building footprints.

For example, according to the strata unit map (Figure 3-5), we know Units 101, 102, 201, 202, 301, 302 are in the bottom-left building. Therefore, we can assign their land and building values into the corresponding footprint.

Figure 3-5: Strata unit map of the area in Figure 3-3.

3.3.2 Without Strata Unit Maps

When strata unit maps are not available, some assumptions are necessary.

3.3.2.1 One Building Associated with Multiple Parcels

The condition where one building is associated with multiple overlapping parcels usually occurs in areas with large apartments. In this case, we will assume the building will contain all the land and building values from the units inside the building. Therefore, the land and building value will be the sum of land and building values from the BCA database, respectively.

3.3.2.2 Multiple buildings Associated with Multiple Parcels

When strata unit maps are not available for the areas where multiple buildings are on multiple overlapping parcels, we first combine the building and land values for the overlapping parcels. This is extremely important for areas with manufactured homes, where manufacture parks themselves will have additional land and building values. Then we assume the buildings in each combined parcel will have the same land and building values.

3.4 Processing Methods: Affected People

Similar to Section 3.3, we utilized two main methods (one for areas with strata unit maps and one for areas without them) in this project to improve the understanding of affected people numbers.

3.4.1 Unit Number Estimation

When strata unit maps are available, it is straightforward to calculate the unit number in a building (as shown in Section 3.3.1). For example, the buildings with strata maps in Figure 3-5 all have 6 units.

When strata unit maps are not available, we utilized the method in Sections 3.3.2.1 and 3.3.2.2. Therefore, when a building is associated with multiple parcels, the unit number of this building is equal to the overlapping parcel number. When multiple buildings are associated with multiple parcels, the average unit number is equal to the ratio between overlapping parcel numbers and building footprint numbers. Note that the average unit number can be smaller than 1 in some areas (e.g., some manufactured home parks). In order to make a more realistic estimation of population density, we further changed the unit numbers of these buildings to 1 as we assume each building will have at least 1 family unit.

For the buildings with the one-to-one building-parcel relationship, we assume that each building will also have 1 family unit.

3.4.2 Estimating Number of Affected People Based on Unit Numbers

We used the numbers of units linked to each building footprint to estimate the number of affected people. For this, we used the 2021 Census, based on dissemination areas (DA), the smallest spatial unit of available census data. Only residential buildings (defined based on BCA data, as well as the City of Courtenay parcel data) were used for this analysis.

First, we calculated the total number of units contained within each DA, to derive an average population per unit. The final stage of the process involved multiplying this number by the quantity of units each building footprint possessed. In doing so, we were able to formulate an estimation of the population for each of the building footprints.

3.5 Challenges & Limitations

Our processing methods have the following limitations:

1. When strata unit maps are not available, our methods assume that building values are distributed evenly within one parcel, which may not always reflect true values for a detailed economic analysis. For example, some units in a building can contain higher economic values because they are larger, have more improvements, etc.
2. This method cannot address relatively small built environments (e.g., sheds and garages). Hence, even if these structures are subject to structural and content damage, they are not considered in the building database after processing.
3. Comparatively, the method using strata unit maps will yield the most accurate results. However, obtaining strata unit maps for various areas can be time-consuming and the information may not be available.
4. This method took into account only units within the floodplain. However, the census dissemination areas are larger, and other buildings footprints outside the floodplain might have multiple units. This might result in an overestimation of the affected number of people within the floodplain, as it gives higher weight to these building footprints.
5. The methods will inherit the limitations of the BC Assessment and building footprint databases. The estimates in BC Assessment may be different from the actual building and land values and not all the buildings are detected in the building footprint database.
6. Limitation in Affected People: Despite a notable improvement in estimating affected people from base counting methods, our method still has limitations related to the quality of census data and the resolution available in terms of population numbers.

3.6 Summary

To perform a building-oriented FRA, it is necessary to integrate land parcel information from BC Assessment and build footprint data. Even though the integration is simple for most of the buildings (single-family homes), additional processing is required for the areas where land use conditions are more complicated (apartments, townhouses, manufactured home parks). We conducted a thorough processing methodology based on whether strata unit maps were available. The methodology greatly increased the accuracy of building-oriented FRA, despite its limitations. Despite some inherited limitations related to census data, this methodology also much improved the estimation of population distribution by correcting unit numbers in each building.

4 Option Analysis – Supporting Information

The following sections provide supporting information on the option analysis. Please refer to the main report for overview and context of the methods.

4.1 Comparison of Available Options – Risk Reduction Measures (Quantitative)

To evaluate different options, a set of decision objectives and performance measures were developed. These included both measures related to risk reduction (i.e., the effect of the option during a flood event), as well as measures related to the effects of the option itself, as well as implementation and maintenance costs and implementability. The focus of this section is on the risk reduction measures, which were quantitatively determined.

As described in the main report, for most of the performance measures related to risk reduction, the average annual loss (AAL) was used (Table 4-1), in consistency with the methods of the quantitative risk assessment analysis. AALs are an estimate of annual impacts averaged over a very long time. They are calculated for each time period by integrating under the risk curve (which considers all five likelihoods that were modelled), see Section 2.3. For the option analysis, the focus was on risk reduction in the mid-term future, but for some options, the present-day was also considered.

Table 4-1: Decision objectives and performance measures, only including risk reduction measures. For the full set of decision objectives and performance measures, please refer to the main report.

	Category	Objectives	Performance Measure
Effect of Option During a Flood	**People (General)**	Reduce risks to health and safety of people	# of all residents in flood extents based on Census 2021 data (Average Annual Loss (AAL) for the mid-term future). % change compared to baseline ('Do nothing').
	People (Socially Vulnerable)	Reduce impacts to socially vulnerable people	Qualitative. Based on NRCan Social Vulnerability data. % change compared to baseline.
	Environment	No risk of contaminant release	# of contamination sources in flood extents (AAL for the mid-term future). % change compared to baseline.
	Culture	Minimize damage of cultural and community sites	# of cultural sites (incl. Indigenous archaeological sites) (AAL for the mid-term future). % change compared to baseline.
	Critical Infrastructure	Minimize failure of critical infrastructure facilities	# of Critical Infrastructure facilities in flood extents (AAL for the mid-term future). % change compared to baseline.

	Category	Objectives	Performance Measure
	Economy	Minimize damage to structures/buildings	Total building values ($) exposed in flood extents, based on BCA 2022 (AAL for the mid-term future). % change compared to baseline.

To estimate the AAL for an option, different assumptions on effectiveness needed to be taken (e.g., a structural option that would protect against up to a specific flood scenario). If an option was assumed to provide protection up to a specific flood scenario, it was assumed that for this flood and any smaller floods (such as more likely scenarios, as well as scenarios with less SLR), no quantitative impacts would occur. This means that for instance the number of affected people and buildings would be zero. For any flood scenarios exceeding this scenario, impacts would still occur and be considered in the AAL calculation.

Assumptions are listed below:

1. **Retreat residential buildings**: Focused on buildings in floodway (5% AEP, present-day).
    a. The residential buildings located in the floodway were removed from the calculation of the AAL for all scenarios (setting both affected people numbers and residential building numbers to zero for locations in the floodway). Note that there will likely be affected people and residential buildings in scenarios with a larger flood extent than the floodway. The AAL calculation considers all five likelihoods that were assessed for each time period.
2. **(Standard) structural protection**: It was assumed that (standard) structural protection is designed to regulatory flood construction level (FCL), i.e., provides protection up to and including 0.5% AEP, mid-term future.
    a. It was assumed that no impacts would occur up to and including the regulatory scenario, i.e., all numbers for affected people, buildings, critical infrastructure, contamination sources, and cultural sites were set to zero for the AAL calculation. Impacts for scenarios larger than the 0.5% AEP, mid-term future (e.g., the 0.2% AEP, mid-term future) were still considered in the AAL calculation.
    b. This assumption applied for dikes, floodwalls, as well as semi-permanent demountable or self-rising structures that are built up to FCL.
    c. Note however that for Local Area 3, while the protection structures (permanent and semi-permanent) are assumed to be up to FCL, there are concerns on the tie-ins at Condensory Bridge, which has an elevation lower (~6 m CGVD2013) than the FCL (~7 m CGVD2013) and would let flood waters enter behind the structure. Therefore, the structures would not provide protection up to FCL, and note that no risk reduction as compared to the baseline was assumed for these structures (in this

case, no additional AAL calculations were carried through, due to the specificity of the situation). See Section 6.5.3.2 in main report for details.

3. **Non-standard structural protection**: It was assumed to be designed to the 5% AEP, mid-term future scenario, i.e., provides protection up to and including for that scenario.
    a. It was assumed that no impacts would occur up to and including the 5% AEP, mid-term future scenario, i.e., all numbers for affected people, buildings, critical infrastructure, contamination sources, and cultural sites were set to zero for the AAL calculation. Impacts for scenarios larger than the 5% AEP, mid-term future (i.e., the 1%, 0.5%, and 0.2% AEP, mid-term future) were still considered in the AAL calculation.

For each of the local areas, the approaches are summarized in Table 4-2. See the main report for description of local areas and more details on options. Note that the risk reduction calculations (AAL) only capture part of the option comparison, further aspects considered in the option analysis included the year-round effect of the option itself, as well as implementation and maintenance costs, and implementability.

Table 4-2: Options and hazard scenarios assessed quantitatively for each of the 6 Local Areas.

#	Local Area Name	Flood Hazard Characteristics	Options	Impacts removed from AAL calculation
1	Tsolum River – Headquarters Road	Riverine (unregulated).	Retreat residential buildings	Affected people/residential buildings in floodway (Present-day – Likely event) removed from all AAL calculations
2	Puntledge River	Riverine (regulated).	Retreat residential buildings	Affected people/residential buildings in floodway (Present-day – Likely event) removed from all AAL calculations
3	Condensory Bridge & Anderton Ave	Riverine, with tidal influence, but limited wave effects.	Protect A: Ring Dike (permanent)	No risk reduction assumed
			Protect B: Concrete Flood Wall (permanent)	No risk reduction assumed
			Protect C: Semi-permanent Demountable/Self-Rising barrier	No risk reduction assumed
			Protect D: Naturalized Foreshore at Anderton Dike	This option was already evaluated in a previous study. Estimates were based on

#	Local Area Name	Flood Hazard Characteristics	Options	Impacts removed from AAL calculation
				McElhanney (2023) report[11]; see that report for details on scenarios and option analysis.
4	Lewis Park & Puntledge Road Commercial Area	Riverine, with tidal influence, but limited wave effects.	Protect A: Ring Dike & Overflow Channel Protect B-1: Full Protection (permanent); concrete flood wall Protect B-2: Full Protection (semi-permanent) Protect C-1: Non-standard Flood wall & Overflow Channel Protect C-2: Non-standard Semi-permanent Protection & Overflow Channel Retreat residential buildings	All impacts removed up to and including the Mid-term Future – Less Likely event. All impacts removed up to and including the Mid-term Future – Less Likely event. All impacts removed up to and including the Mid-term Future – Less Likely event. All impacts removed up to and including the Mid-term Future – Likely event (5% AEP). All impacts removed up to and including the Mid-term Future – Likely event (5% AEP). Affected people/residential buildings in floodway (Present-day – Likely event) removed from all AAL calculations.
5	Courtenay River – Cliffe Avenue Corridor	Riverine, with tidal influence, but limited wave effects.	Protect - Vertical Flood Wall Retreat commercial and residential buildings	All impacts removed up to and including the Mid-term Future – Less Likely event. Affected people, and residential and commercial buildings in floodway (Present-day – Likely event) removed from all AAL calculations.
6	Airpark & South Courtenay	Coastal-riverine conditions (Courtenay River below 21st	Protect A: Flood Wall	All impacts removed up to and including the Mid-term Future – Less Likely event.

[11] McElhanney (2023) 'Anderton Dike Wall Options Analysis Final Report – Issued for Use'. Prepared for the City of Courtenay.

#	Local Area Name	Flood Hazard Characteristics	Options	Impacts removed from AAL calculation
		Street) & coastal (estuary).	Protect B: Green Shores (erosion protection) Protect C: Dike with Riprap Banks Retreat residential buildings in present-day likely flood extent Retreat all buildings in coastal erosion setback	No risk reduction assumed, as focus on erosion protection. All impacts removed up to and including the Mid-term Future – Less Likely event. Affected people/residential buildings in Present-day – Likely event removed from all AAL calculations. All buildings/affected people in coastal erosion setback (see main report for details) removed from mid-term future AAL calculations.

In addition to the various risk reduction options discussed above, a baseline scenario was also considered for the purposes of comparison. This represented the "do-nothing" option, or the expected flood damages if no additional flood mitigation measures were implemented beyond those already in place. Then the AALs of the various receptors for each option were compared to the AAL for the baseline. This was done by calculating the percentage change in AAL from the baseline to each option (Table 4-3). This provided a quantitative measure of how much each scenario could reduce the expected annual losses from flooding for each receptor compared to doing nothing.

Quantitative AAL calculations applied mostly to *Protect* options and *Retreat* options. For *Accommodate* options, generally a moderately effectiveness was assumed, given that these options can reduce some risk, but not all. Note that *Avoid* and *Resilience-building* options were not evaluated as part of the strengths and weaknesses tables for local areas, as they are generally recommended city-wide.

Table 4-3: Risk Reduction Scale

Very ineffective	Ineffective	Moderately effective	Effective	Very effective
No risk reduction compared to baseline	0-25% risk reduction compared to baseline (e.g., 0-25% less people affected)	25-50% risk reduction compared to baseline	50-75% risk reduction compared to baseline	75-100% risk reduction compared to baseline

Note that the same software was used for this analysis, as listed in Section 2.4.

4.2 Challenges & Limitations

Given the information, timing, and resources available to complete this project, there were challenges and limitations to the work completed. The limitations stated below are specific to the estimation of risk reduction performance measures, as discussed in this section. For further limitations, please refer to the main report.

1. Data Availability and Accuracy: The accuracy of quantitative measures at the local level heavily depends on the availability and precision of data. See Section 2.5 for details on limitations.
2. The scoring of the quantitative measures was performed comparatively to the baseline. That means that the results are sensitive to the number of identified elements/buildings/infrastructure pieces exposed for each receptor. This might lead to overestimation or underestimation of the provided score.
3. The scoring for Local Area 3, and more specifically on the Anderton Dike option was based on the conclusions of the McElhanney (2023) and NOT on a quantitative analysis as it was not within the scope of this work. Relevant results were provided for engagement purposes only, after coordination with the City staff.

5 Conclusion

This appendix includes details on the methods employed throughout the risk assessment, data processing, and option analysis. The findings are presented systematically in the main report. For more granular details or specific datasets, please refer to the attachments to this appendix (spreadsheets; spatial data package).

6 References

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