CITY OF CAMPBELL RIVER
SEA LEVEL RISE STUDY
PHASE 2 – ESTUARY ASSESSMENT

FINAL REPORT

Prepared for:

City of Campbell River

December 11, 2018

NHC Ref. No. 3003194

nhc
northwest hydraulic consultants
water resource specialists

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City of Campbell River
City of Campbell River, BC

Prepared by:

Northwest Hydraulic Consultants Ltd.
North Vancouver, BC

Revised:
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NHC Ref No. 3003194

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EXECUTIVE SUMMARY

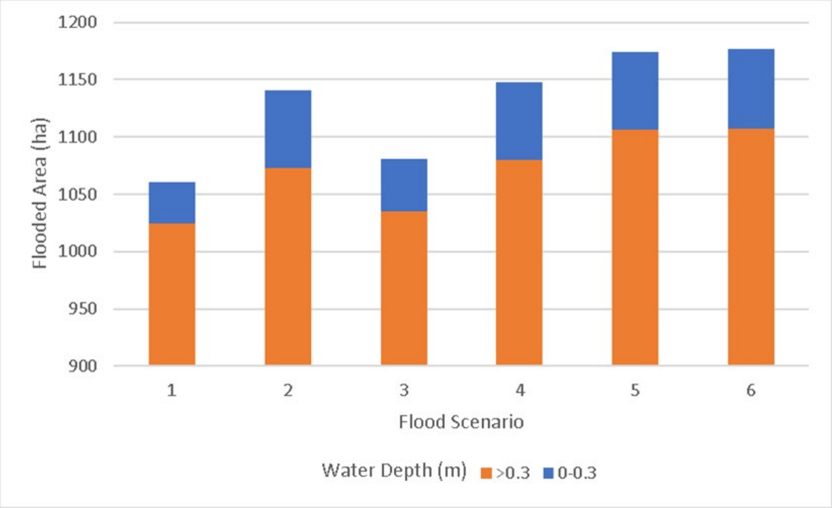
The Flood Construction Levels currently available for the Campbell River estuary area are from the 1989 floodplain mapping study undertaken by Klohn Leonoff Consulting Engineers which utilized a one-dimensional hydraulic model and did not consider sea level rise. The objective of this study is to re-examine the flood levels and extents in and around the Campbell River estuary with a detailed two-dimensional hydrodynamic model and with consideration of both river discharges and coastal flood levels (tides, storm surge, and sea level rise). The results are not expected to be considered as official floodplain mapping but are to serve as a high-level planning tools for the City to assess potential impacts and risks in the Campbell River estuary.

The Campbell River estuary is located on the edge of Discovery Passage on the east coast of Vancouver Island. The seaward boundary of the estuary consists of a low sandspit ending at Tyee Point and a large drying shoal. The tidal influence ends in the river rapids below the Highway 19 Bridge, 2.5 km upstream from Tyee Point. The river flow into the estuary is primarily from the John Hart Power Generating Station, located about 5 km upstream from the mouth, with additional flows from the Quinsam River, located 1.5 km downstream of JHT. Flood hazards in the estuary are driven by the interaction of coastal processes (high tides, storm surge, and sea level rise) with riverine processes (flood discharges).

Flood levels and extents in and around the estuary with consideration of tides, storm surge, and sea level rise, and river discharges were evaluated using TELEMAC-2D model. TELEMAC-2D is a two-dimensional (2D) model that solves the Saint-Venant equations using the finite-element method and can perform transient simulations where conditions are changing over time. The model simulates free-surface flows in two dimensions of horizontal space. The model domain extends from JHT (upstream boundary) to a section of Discovery Passage (downstream boundary) and includes a portion of the Quinsam River. The model mesh consists of approximately 102,000 nodes and 202,000 elements. The element lengths vary from approximately 50 m near the Discovery Passage boundaries and to about 5 m in the river. The model was validated using measured river gauge data and tide data for a ten-day period in November of 2016 during which high rainfall and large tides occurred.

Model scenarios were undertaken with sea level rise allowances for the years 2017, 2050, and 2100. For each year (or allowance for sea level rise) two different scenarios of combinations of river discharge and storm surge were examined; a 20-year return period river discharge coupled with a 10-year return period storm surge, and a 200-year return period discharge coupled with a 1-year return period surge. The modeling found that variations in river discharge have a significant influence on flooding in Campbell River at present day sea levels while in the future the variation in the extent of flooding reduces as more of the estuary floods from the influence of sea level rise.

The inundation areas are divided into two segments: one with a maximum water level less than 0.3m, and one with a maximum water level greater than 0.3m. This separation differentiates between areas which have the potential to be significantly affected by floodwaters and areas where inundation is expected to be of lower consequence.



Flood Scenario

1. SLR = 2017, 20-yr River Discharge, 10-yr Surge
2. SLR = 2017, 200-yr River Discharge, 1-yr Surge
3. SLR = 2050, 20-yr River Discharge, 10-yr Surge
4. SLR = 2050, 200-yr River Discharge, 1-yr Surge
5. SLR = 2100, 20-yr River Discharge, 10-yr Surge
6. SLR = 2100, 200-yr River Discharge, 1-yr Surge

It is observed that the overall flooded areas are very similar for both scenario 5 and 6, but it is noted that there are differences in the locations that flood. Scenario 5 is for a 20-yr flood discharge in the river combined with a 10-year storm surge level in Discovery Passage, while in scenario 6 the river discharge is for a 200-yr event and the ocean level is only bound by a 1-yr storm surge.

In scenario 5 there is more flooding near Spit Road and the Discovery Harbour Shopping Centre area, while in scenario 6 this area remains mostly dry while the neighbourhood adjacent to Hwy 19 on the north side of the river (the estuary) experiences increased flooding. (See Figure E-1-1)

An effective mitigation strategy evaluates a variety of options to develop a protection strategy appropriate for the site. The potential mitigation approaches include the broad categories of accommodate, protect, retreat, and a combination of the above. As part of this study NHC considered specific mitigation measures for nine locations which experience flooding. The mitigations range from straightforward measures such as raising existing roadways and ensuring stormwater systems are functional, to more extensive mitigations that include land acquisition and retreat.

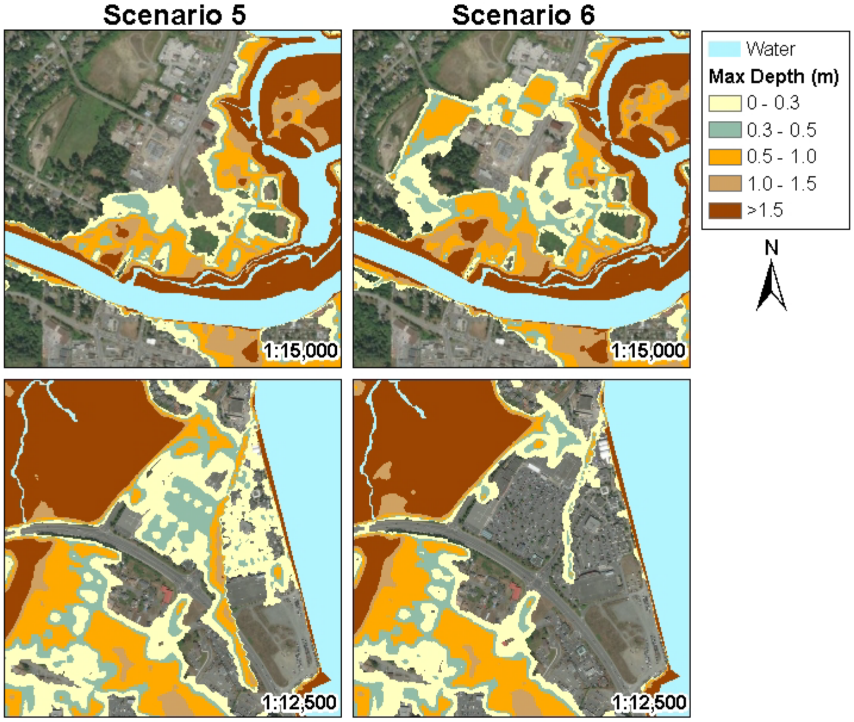


Figure E-1-1: Flooding depths for two scenarios (5 and 6) for the river near the highway crossing (top) and for the downtown shoreline at the Discovery Harbour Marina (bottom)

A notable area that is a source of flooding in all scenarios into commercial and residential areas of the downtown is at the Campbell River Lodge (1760 Island Highway, Campbell River). Mitigations at this location will have a large impact on reducing flood risk. Construction of a river dike along the bank at this location could reduce the potential for overflows and related flooding although there are a number of constraints.

General constraints associated with all engineered protections include:

- requirement for a significant right of way,
- impact on fish and wildlife habitat adjacent to erosion protection works,
- possible localized effects on flood levels or erosion due to channel constriction and deflection associated with protection works,
- internal drainage considerations behind the diked barrier,
- significant construction costs,
- regulatory approvals from the Federal and Provincial governments, and
- ongoing maintenance costs.

To be effective, a dike has to tie into high ground on either end.

All mitigation options should be considered in conjunction with a community planning project which examines future land-use plans. Some of the constructed flood mitigation options considered may be deemed to be infeasible due to cost or required space constraints. In those cases, planning can facilitate accommodation or retreat measures such as SLR zoning which can be implemented effectively over the time horizon that sea level rise is expected to have significant impact on flood levels.

This study has examined coastal flood hazard in the Campbell River Estuary for sea level rise up to 1 m in elevation (year 2100 levels as per BC guidance) while long-term planning levels for sea level rise for are set at 2 m. It is thus recommended that when considering the findings of this study, planners keep in mind that sea level rise is not expected to stop at 1 m but to continue upwards. This study shows extent of flooding within the estuary, and how flood patterns are expected to change in time between present day and year 2100.

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1 INTRODUCTION

The City of Campbell River (the City) is located on the east coast of Vancouver Island on Discovery Passage at the northern end of the Strait of Georgia, and along the estuary of the Campbell River. Much of the development in the city is concentrated in lands that are only 4 m above sea level. The community has faced flood and erosion hazards both along its riverfront from high river flows and oceanfront from king tides and storm surge.

The Province of British Columbia issued Guidelines in 2011 on flood hazard land use management that included direction related to sea level rise (SLR). Studies by BC Ministry of Environment (2011b) indicate that there will be a significant impact to coastal BC over the next century. Based on a review of scientific literature, global sea level rise from the year 2000 was estimated to be 1 m by the year 2100 and 2 m by 2200, and this guidance has been incorporated into the provincial guidance for Flood Hazard Area Land Use Guidelines (January 2018 update).

The City recognizes that being a coastal city with limited flood protection infrastructure, the risks can be significant, and that the hazard and consequence posed by anticipated future coastal and river flooding may be better dealt with by using a combination of adaptation strategies, land-use changes and structural and non-structural approaches. Prior to developing such recommendations, the City sought to understand the potential extent and hazard posed by future flood scenarios, vulnerabilities in the Campbell River estuary area, and anticipated consequences.

The Flood Construction Levels (FCLs) currently available for the Campbell River estuary were from the 1989 floodplain mapping study (Klohn Leonoff Consulting Engineers, 1989) which utilized a one-dimensional hydraulic model and did not consider sea level rise. The objective of this study is to re-examine the flood levels and extents in and around the estuary with a more detailed two-dimensional hydrodynamic model and with consideration of storm surge and sea level rise. The results of this study are not to be considered as official floodplain mapping[1], but will instead serve as a high-level planning tool for the City to assess potential impacts and risks in the Campbell River estuary.

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[1] To develop official floodplain maps from the model results requires following legal standards as outlined in EGBC's Professional Practice Guidelines Flood Mapping in BC (EGBC, 2017). Specifically: the flood design standard in the area must be verified and made consistent with the model scenario used; appropriate freeboard must be added to the modelled water levels; the floodmap must be compared to previous floodmapping and local flood hazard zoning (including a possible field investigation of any changes); and the map must be ratified by local government.

2 SITE CHARACTERIZATION

2.1 Physical Setting

The Campbell River estuary is located in the Discovery Passage on the east coast of Vancouver Island. The seaward boundary of the estuary consists of a low sandspit ending at Tyee Point and a large shoal that is exposed during low tide (**Figure 2-1**). The tidal influence ends in the river rapids below the Highway 19 Bridge, 2.5 km upstream from Tyee Point (Ages and Woollard, 1991).

The river flow into the estuary is primarily from the John Hart Power Generating Station (JHT), located about 5 km upstream from the mouth, and from the Quinsam River, located 1.5 km downstream of JHT. The river drains into the strong tidal currents of Discovery Passage and mixes almost immediately with the seawater.

Figure 2-1: Project site, Water Survey of Canada (WSC) and Fisheries and Oceans Canada (DFO) gauge locations.

2.2 Oceanographic, Meteorological and Hydrological Conditions

Flood hazards in the estuary are driven by the intersection of coastal processes with riverine processes. Specifically, the altered flow regime produced by operation of the dams upstream and interaction with tide, storm surges and sea level rise. These processes are discussed in the following sections.

Tides

Tides near Campbell River are mixed semidiurnal with an annual mean tidal range of 2.7 m and a large tidal range of 4.9 m. Two months of predicted hourly tidal elevations at Campbell River are shown in Figure 2-2, illustrating the bi-weekly tidal variability.

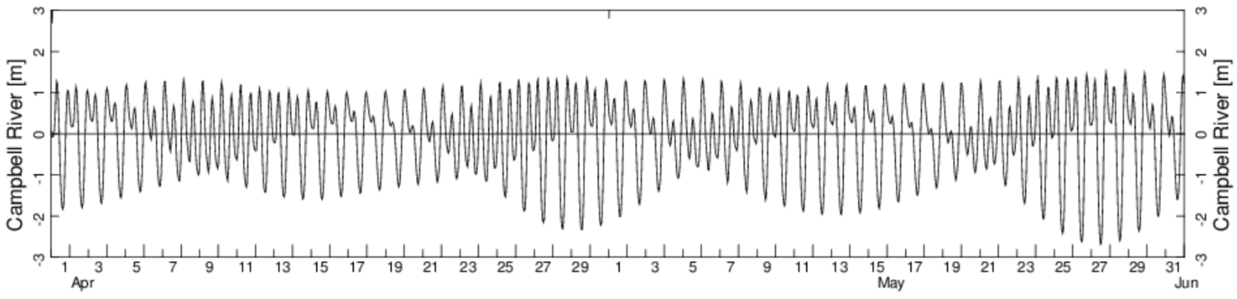

Figure 2-2: Predicted tides at Campbell River from April 1st to May 31st, 2017.

Table 2-1 presents local tidal water levels based on values obtained from Campbell River from 2017 Canadian Tide and Current Tables Volume 6.

Table 2-1: Summary of Campbell River Tide elevations (Source: Canadian Hydrographic Service)

Sea State	Tide Elevation (m Geodetic Datum)
Higher High Water, Large Tide (HHWLT)	1.7
Higher High Water, Mean Tide (HHWMT)	1.2
Mean Water Level (MWL)	0.0
Lower Low Water, Mean Tide (LLWMT)	-1.5
Lower Low Water, Large Tide (LLWLT)	-2.5

Storm Surge

Storm surge is caused by weather effects (wind setup, wave setup, atmospheric pressure uplift) on the ocean. The design storm surge values were calculated from Campbell River water level data (1972 to 2016) by first removing the tidal component from the measured water level to obtain the tidal residual. Extreme Value Analysis (EVA) was then conducted using the "Peak Over Threshold" method by considering tidal residual[2] values occurring when tides were greater than HHWLT. The results are summarized in the table below.

Table 2-2: Summary of design storm surges

Return Period (yr)	Storm Surge (m)
1	0.49
2	0.57
5	0.66
10	0.72
20	0.78
50	0.86
100	0.91
200	0.97

Note that the maximum observed water level over the 45 years record was 2.45 m Geodetic Datum (GD) which is 0.75 m above HHWLT.

Sea Level Rise

The sea level rise policy for BC (2011b) recommends assuming a 1 m rise in global mean sea level between the year 2000 and 2100 as show in **Figure 2-3**.

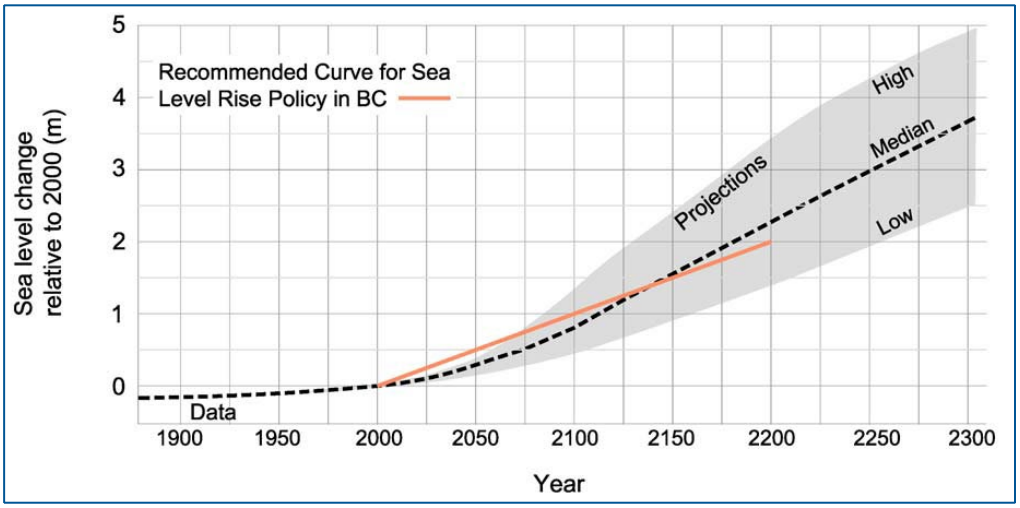

Figure 2-3: Projections of global sea level rise (2011b).

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[2] Tidal residual (aka tidal surge) is the difference between the predicted astronomical tide and the actual observed tide levels. This difference is the result of many local, regional and sometimes global environmental factors. The most significant of these factors tend to be atmospheric conditions; specifically wind speed, wind direction and atmospheric pressure.

As part of this study, the impacts of sea level rise were assessed for the years 2050 and 2100. It should be recognized that there is significant uncertainty in sea level rise projections with a range in the rise presented in the draft provincial sea level rise policy and shown in **Figure 2-3**, from about 0.5 m to 1.3 m by 2100 and 1.4 m to 3.4 m by 2200. At the time of the preparation of the provincial guidance (during 2009 and 2010 time periods) a 1.0 m sea level rise estimate by 2100 was considered to be in the upper range of projections while a 2.0 m rise estimate by 2200 was toward the low to mid-range of projections. It should be recognized that in the subsequent years, additional studies (Han et al. 2016) suggest that the upper limit for sea level rise may be higher than previously estimated, and that 1.0 m of SLR by 2100 may not be as conservative a planning level as previously thought.

Given these uncertainties, reliance on interpolation of simulation results, rather than detailed simulation of finer increments of sea level rise, is considered to be a reasonable and an appropriate approach for intermediate and long-range planning purposes. It is recommended that the City monitors changes in climate change science and sea level rise estimates and adapt their flood management plans accordingly.

River Discharge

The river flow into the Campbell River estuary is primarily from JHT, located about 5 km upstream from the mouth, and from the Quinsam River, located 1.5 km downstream of JHT.

The maximum discharge capacity of the JHT's existing three-bay spillway is approximately 1,630 m^3/s at the maximum reservoir level of El. 141.73 m. The proposed overflow spillway at JHT will provide an additional discharge capacity of about 350 m^3/s at reservoir El. 141.73 m[3]. A recent Water Use Plan (BC Hydro, 2012) was implemented in November 2012. Thus, JHT releases prior to then are not indicative of future releases. Average daily discharge for the period between 2013 and 2016 from WSC gauge station 08HD003 (Campbell Rive near Campbell River), located 1.5 km downstream of JHT, is 89 m^3/s. Further downstream, the river is joined by the Quinsam River, which has mean annual daily flow of 9 m^3/s, resulting in a total average daily inflow to the estuary of about 100 m^3/s.

Estimating a return period for outflows from JHT involves a combination of simulation and probability analysis using a probability tree method (Klohn Leonoff Consulting Engineers, 1989). BC Hydro indicates that the dam system operations to mitigate flood risk have not changed significantly[4] over the years (per. comm. S. Watson, January, 2018). As such, values derived from the 1989 floodplain mapping were adopted for this study (**Table 2-3**).

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[3] These are not design discharges but rather the maximum discharge capacity of the existing and proposed spillways at JHT.

[4] The 2012 BC Hydro Campbell River System Water Use Plan provides preferred low and high flows and fisheries target flows for the Lower Campbell River, including 'pulse' flows. Of concern to this study are the extreme flood flows and overall rating curve for the system which relate to spillway and reservoir levels.

Table 2-3: Frequency analysis of maximum daily flows (Klohn Leonoff Consulting Engineers, 1989)

Return Period (yr)	Exceedance probability	John Hart dam Release (m^3/s)	Quinsam River (m^3/s)	Total (m^3/s)
20	0.05	1,084	136	1,220
200	0.005	1,340	233	1,573

3 ESTUARY FLOOD ASSESSMENT

Flood levels and extents in and around the estuary with consideration of tides, storm surge, and sea level rise were evaluated using TELEMAC-2D model. TELEMAC-2D is a two-dimensional (2D) model that solves the Saint-Venant equations using the finite-element method and can perform transient simulations where conditions are changing over time. The model simulates free-surface flows in two dimensions of horizontal space. At each node in the computational mesh, the program calculates the depth of water and depth-averaged velocity. The equations and model descriptions are provided in detail in (Hervouet, 2007).

3.1 Modelling Methodology

The model domain (**Figure 3-1**) extends from JHT (upstream boundary) to Discovery Passage (downstream boundary) and includes a portion of the Quinsam River. The model mesh consists of approximately 102,000 nodes and 202,000 elements. The element lengths vary from approximately 50 m near the Discovery Passage boundaries and to about 5 m in the river. The model elevations in Geodetic Datum (GD) were derived using the following datasets:

- 2006 bathymetric survey data collected downstream of Highway 19 Bridge by BC Hydro;
- 2007 tailrace and Canyon bathymetry data provided by BC Hydro;
- 2009 survey cross sections collected upstream of Highway 19 Bridge by BC Hydro;
- 2011 LiDAR provided by BC Hydro;
- 2016 LiDAR provided by City of Campbell River; and
- Canadian Hydrographic Service (CHS) hydrographic chart 3540.

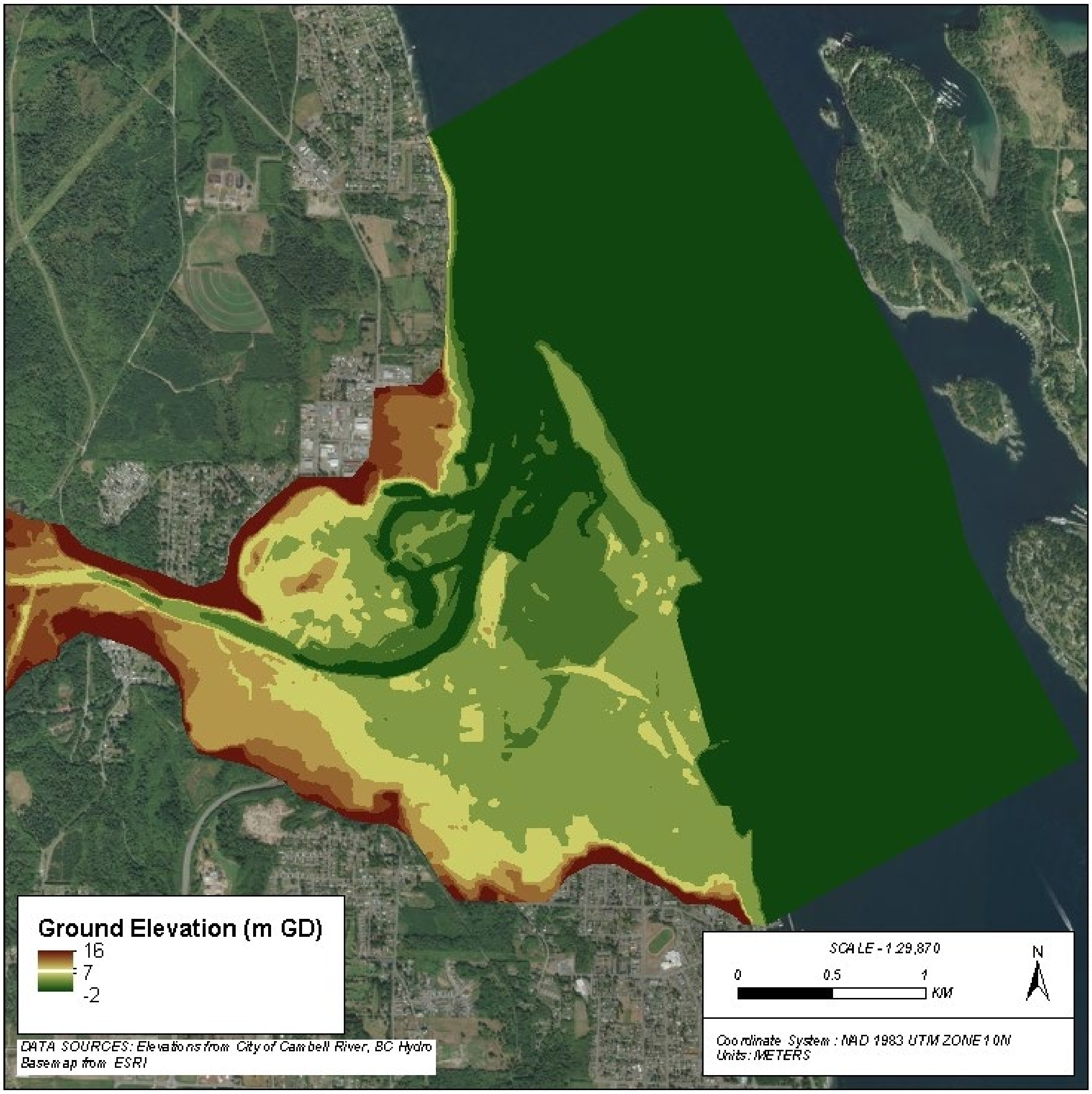

Figure 3-1: TELEMAC model mesh extent (note: depths in Discovery Passage 2 m or lower as per bathymetric data for area.)

Bed surface roughness coefficient (Manning's n value) represent the flow resistance due to various sources of energy loss. General bed roughness values are summarized in the following table.

Table 3-1: Bed roughness resistance values

Description	Manning's n
River	0.04 – 0.045
Forest	0.09
Developed area	0.05
Open and undeveloped area	0.035
Offshore Seabed	0.012 – 0.024

The upstream boundary conditions include JHT tailrace and Quinsam River flows. Measured water level elevations at DFO Station 8074 are used for the downstream boundary conditions. In addition, existing culverts on the Lower Reach of Nunns Creek at 16th Avenue, Old Island Highway and Discovery Highway were implemented in the model based upon information provided by the City of Campbell River (McElhanney et al., 2004).

3.2 Model Validation

Daily discharges from WSC Station 008HD003 (Campbell River at Campbell River) between 1992 and 2016 are shown in **Figure 3-2**. The largest event that occurred in recent years was in November 2016 with a maximum flow of 623 m^3/s. Hourly time series of JHT discharge and Campbell River water level between November 5th and 15th, 2016 are shown in **Figure 3-3**. This high flow event was used for validation of the model.

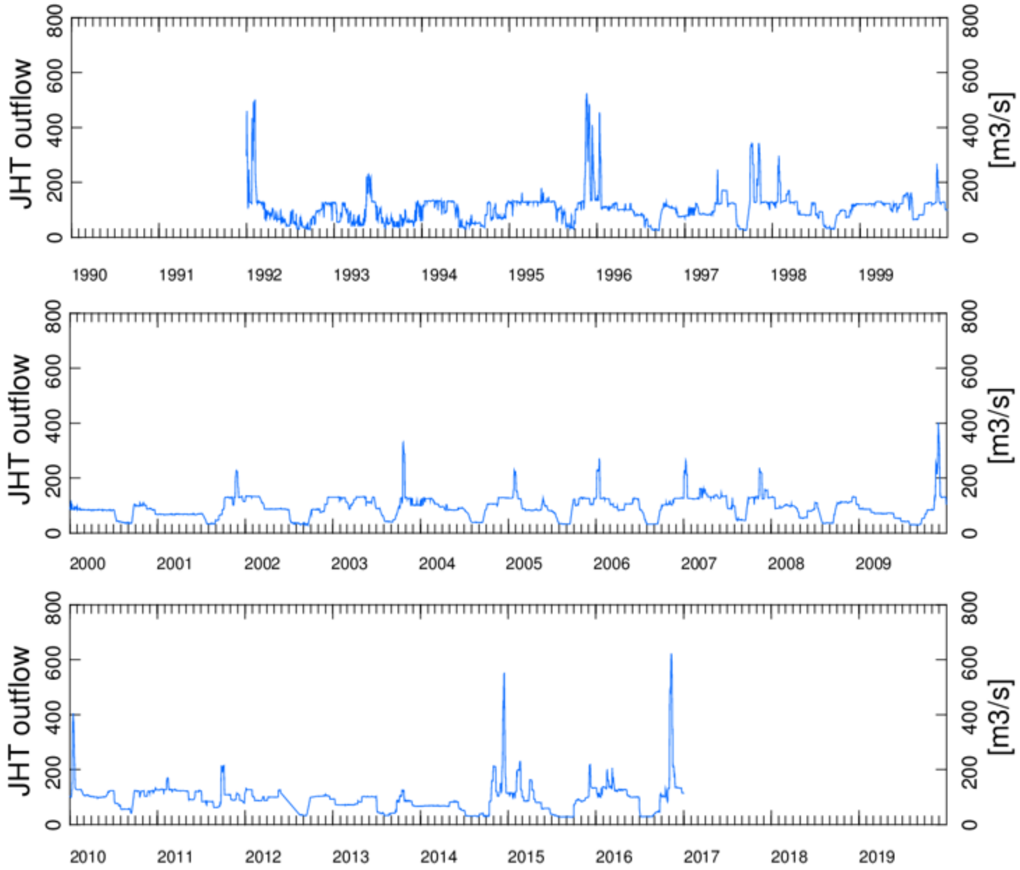

Figure 3-2: Daily discharge from WSC Station 08HD003 (Campbell River at Campbell River)

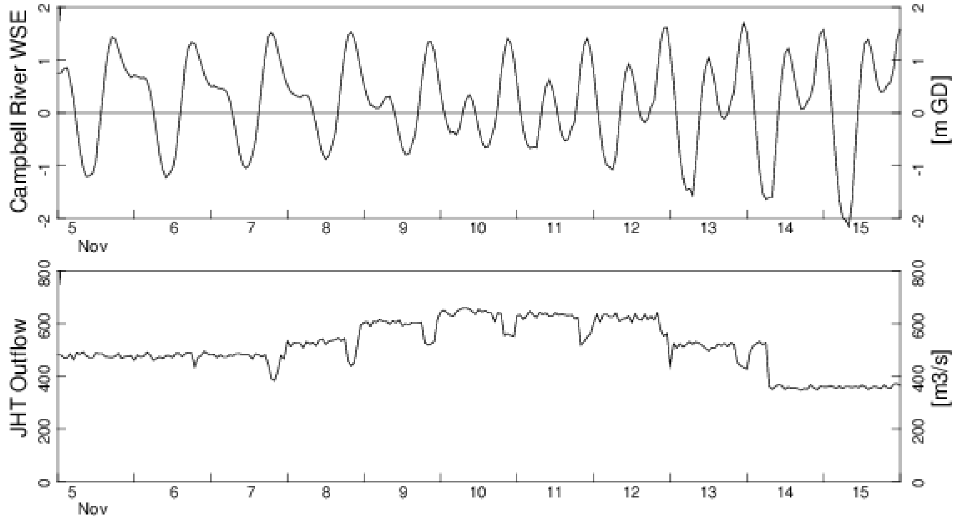

Figure 3-3: JHT discharge and Campbell River water surface elevation for November 5th – 15th, 2016

Observed (red line) and modelled (blue line) hourly water levels between November 5th and 15th, 2016 at WSC 08HD003 (Campbell River at Campbell River) shown in the top panel and 08HD022 (Campbell River at Campbell River Lodge) shown in the bottom panel are compared in **Figure 3-4**.

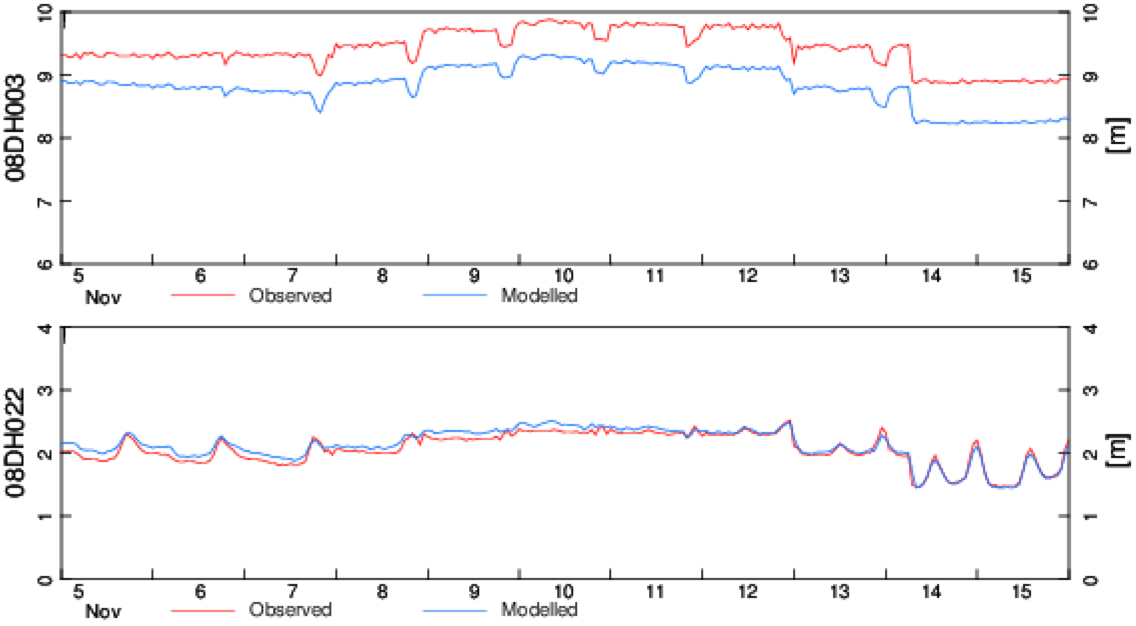

Figure 3-4: Observed and computed water levels at 08HD003 (Campbell River at Campbell River) and 08HD022 (Campbell River at Campbell River Lodge)

The results show poor agreement between observed and modelled water levels at 08HD003 (Campbell River at Campbell River). The root-mean-squared error (RMSE) and mean bias error (MBE) values between observed and modelled water levels are 0.59 m and -0.59 m, respectively. According to information provided by WSC, the conversion between published water level data and GD is approximately 6.814 m. Comparing the published value and field data collected by NHC on March 11, 2011, the conversion value should be 6.12 m instead of 6.814 m. Using this correction, the RMSE and MBE values between observed and modelled water levels are 0.13 m and 0.02 m, respectively. Observed (red line) and modelled (blue line) hourly water levels between November 5th and 15th, 2016 at WSC 08HD003 with the revised conversion value is compared in **Figure 3-5**.

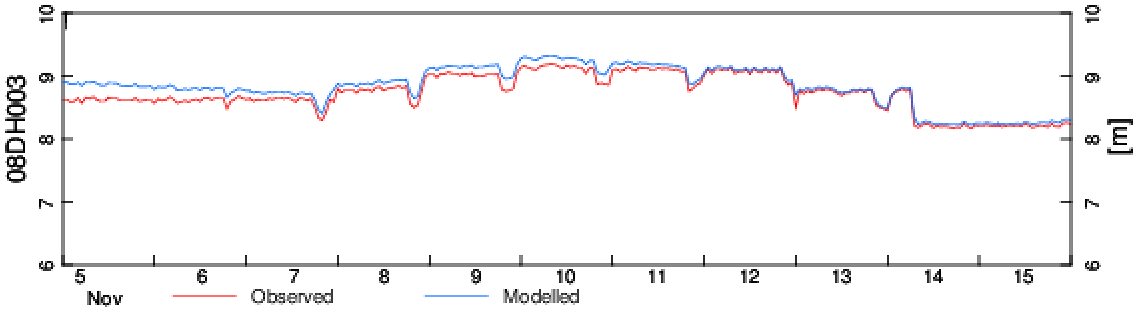

Figure 3-5: Water level comparison between modelled and observed water level at 08HD003 using revised conversion value.

The results indicate a good agreement between observed and modelled water levels at 08HD022 – Campbell River at Campbell River Lodge. The RMSE and MBE values between observed and modelled water levels are 0.08 m and 0.06 m, respectively.

The differences between modelled and measured water levels at 08HD003 and 08HD022 are typically within ±0.10 m. This difference is within the natural variability[5] of the system. Other sources of uncertainties could be associated with reported powerhouse discharge which was based on readings from flow metres and limited bathymetry data available between Highway 19 Bridge and Tyee Point. The calibration results could be improved by adjusting local bed roughness values. Sensitivity analysis shows that changes in discharge by ±5 % would lead to less than 0.10 m changes in predicted water level. Changes in overall channel bed roughness values by ±5 % would also lead less than 0.10 m changes in predicted water level.

3.3 Model Scenarios

The objective of this study to examine the flood levels and extents in and around the estuary with consideration of high river flow coinciding with storm surge and sea level rise. Three time horizons were considered: 2017, 2050 and 2100. The corresponding HHWLTs are 1.87 m GD, 2.3 m GD and 2.7 m GD respectively.

Two river discharge events were considered for each time horizons: 20-yr and 200-yr. It is assumed that the river discharge and storm surge are independent of each other for this study. The storm surge values corresponding to each river discharge event were selected such that the probability of exceedance of the two events is equals to 0.05 (i.e., 200 year return period). Six scenarios were examined. Key hydraulic conditions for each scenario are summarized in **Table 3-2**.

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[5] Natural variability – refers to the randomness observed in nature.

Table 3-2: Summary of modelled scenarios

Scenario	Year	Maximum Discharge (m^3/s)	Discharge return period (yr)	HHWLT (m GD)	Sea level rise (m)	Storm Surge (m)	Storm Surge return period (yr)
1	2017	1220	20	1.7	0.17	0.72	10
2	2017	1573	200	1.7	0.17	0.49	1
3	2050	1220	20	1.7	0.50	0.72	10
4	2050	1573	200	1.7	0.50	0.49	1
5	2100	1220	20	1.7	1.00	0.72	10
6	2100	1573	200	1.7	1.00	0.49	1

Historical discharge data from WSC station 08HD003 (Campbell River at Campbell River) indicates that the duration of high river/reservoir discharge events ranges between 5 to 10 days. A 16-day synthetic design event period was generated with consideration of the general tidal and discharge characteristics of the Campbell River estuary. It is important to note that this is a simplistic and conservative estimate of storm duration extrapolated to the respective discharges associated with selected return periods.

While the extent and depths of flooding are representative of the 20-yr and 200-yr events, the duration of flooding in the model results has limited accuracy without further analysis of operation scenarios for the John Hart facility. **Figure 3-6** shows the time-series of hydraulic conditions adopted for Scenario 1 – Year 2017 with 20-yr discharge event and 10-yr storm surge. The hydraulic conditions for Scenarios 2 to 6 are similar in duration but with different peak discharges and water levels.

That rational for the choice of return period combinations was taken to examine a range of flooding due to combinations of river discharge and ocean levels within the scope of the study. Assuming independence, the combination of a 1 in 20 year river discharge event and a 1 in 10 year storm surge gives the same 1 in 200 year probability as the 1 in 200 year river discharge coincident with a 1 in 1 year storm surge.

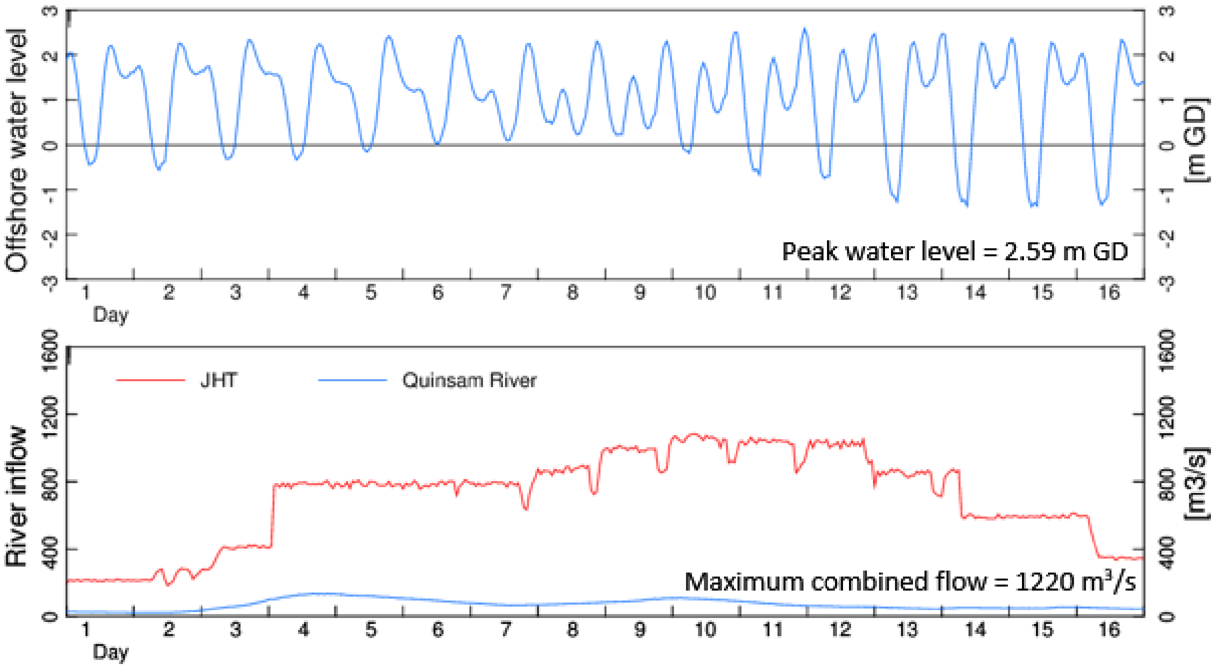

Figure 3-6: Hydraulic conditions for Year 2017, 20yr discharge with 10yr storm surge

3.4 Model Results

To assist the City in assessing potential impacts and risks in the Campbell River estuary, maximum flood extent and depth map as well as hazard rating map were prepared for each scenario. The depths shown on the maximum flood extent and depth maps are classified into the categories shown in **Table 3-3**. These categories are based on information in the Cowichan Valley Emergency Preparedness Workbook (2017).

Table 3-3: Mapped Water Level Classes

Depth (m)	Description
0 – 0.3	0.15 m of moving water can make a person fall and will reach the bottom of most passenger cars causing loss of control and possible stalling and 0.3 m of water will float most vehicles.
0.3 – 0.5	most houses are dry; walking in moving water or driving is potentially dangerous; basements and underground parking may be flooded, potentially causing evacuation
0.5 – 1.0	water on ground floor; basements and underground parking flooded, evacuation of residents expected; electricity failed; vehicles are commonly carried off roadways
1.0 – 1.5	ground floor flooded; residents evacuate
>1.5	first floor and often roof covered by water; residents evacuate

Impacts from flood water are dependent on the velocity as well as the depth of the water. The faster the water, the more damage it can do and the higher risk it can pose to people. A hazard rating was developed based on the model's depth and velocity outputs. The hazard ratings shown on the hazard rating maps following are classified into the categories shown in **Table 3-4**. These classifications are based on a UK hazard rating classification framework which is provided in the APEGBC[6] guidelines for Flood Mapping in BC. This hazard to people formula combines water depth, velocity and a debris factor through the following formula: Hazard Rating = Depth x (Velocity +0.5) + Debris Factor. There were no debris factors accounted for as these are outside of the scope of this analysis. The maps display the hazard rating as determined through this formula and improve the understanding of the potential hazard posed by the floodwaters by incorporating velocity model results. The hazard model is subject to the same constraints as the flood mapping.

Table 3-4: Hazard to People Classifications (APEGBC, 2017)

Rating	Description
< 0.75	Very low hazard (caution)
0.75 – 1.25	Danger for some (includes children the elderly and the infirm)
1.25 – 2.00	Danger for most (includes the general public)
>2.00	Danger for all (includes emergency services)

The model results identify flooding patterns. As shown by scenario 1 and 2, when river discharge is increased to the 200 year flood period, water levels in the downtown area increase, even with a consistent sea level. When river discharge is consistent at the 20 year return period (scenarios 1, 3 and 5), the increase in sea level increases flood extents and depths. With 0.5m of SLR, the increase in flood extents is primarily around the edges of the flooding along the estuary and creek areas. With a 1.0m SLR, the flood extents increase significantly to include the downtown area. Increases in sea level rise have minimal impact on the upstream flooding along Campbell River past the highway crossing.

Figure 3-7, **Figure 3-8**, **Figure 3-9** and **Figure 3-10** show the maximum flood extent and depth, and the maximum hazard rating for scenario 1 (Year 2017, 20-year discharge with 10-year storm surge) and scenario 2 (Year 2017, 200-year discharge with 1-year storm surge). The figures show that the flood extent in the Campbell River estuary is greater under scenario 2 than under scenario 1. The maximum water surface elevations near the Campbell River Lodge, a location where flooding has frequently occurred, were 3.5 m GD and 3.8 m GD under scenario 1 and 2, respectively. By comparison, the water surface elevations presented in the 1989 Klohn Leonoff study near Campbell River Lodge were 3.7 GD and 4.3 m GD for 20 year discharge with no storm surge and sea level rise and 200 year discharge at Higher High Water Large Tide (with no storm surge and no sea level rise allowance).

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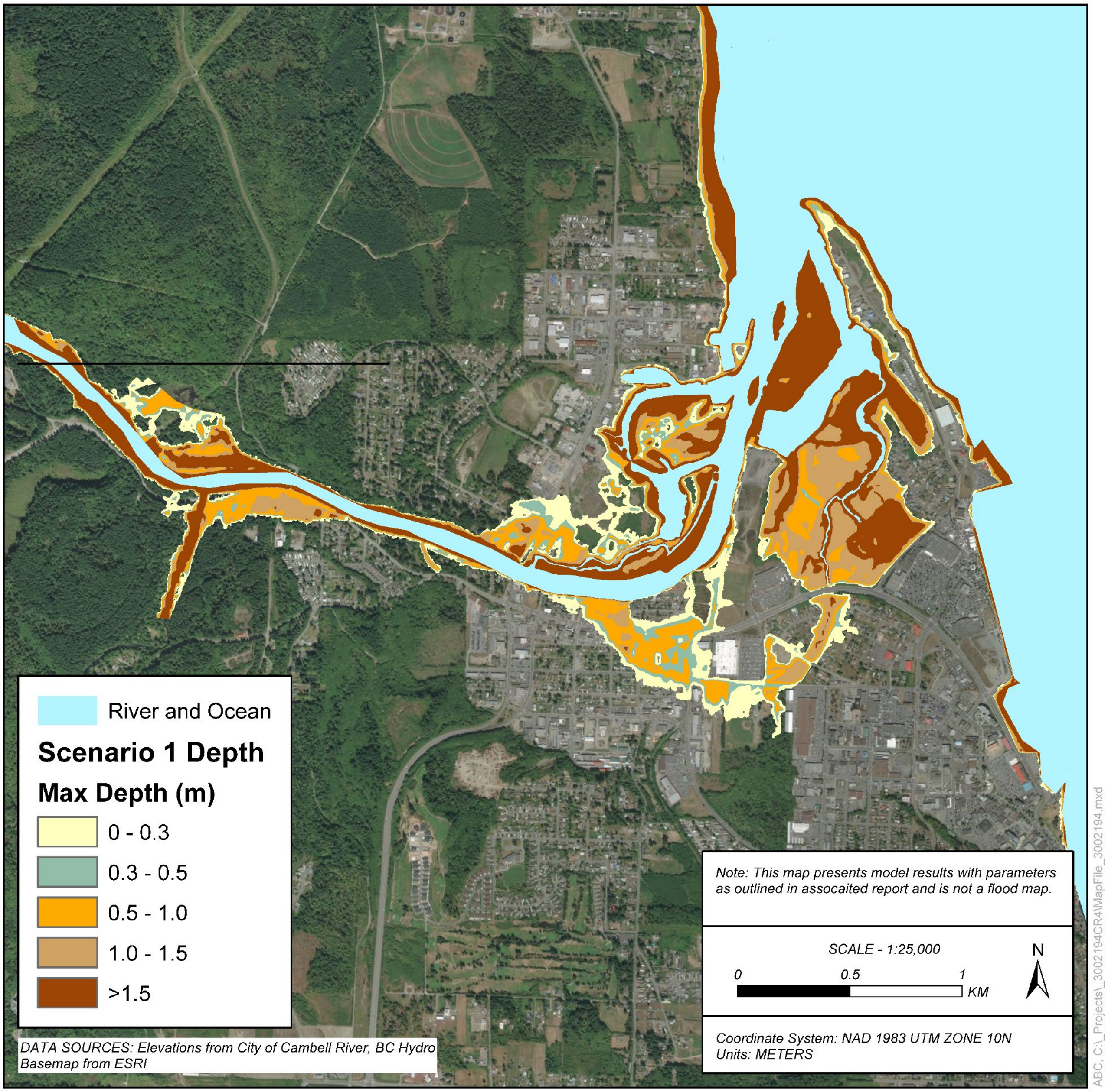
[6] now Engineers & Geoscientists British Columbia (EGBC)



Note: This map presents model results with parameters as outlined in assocaited report and is not a flood map.

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METERS

DATA SOURCES: Elevations from City of Cambell River, BC Hydro
Basemap from ESRI

Figure 3-7: Maximum flood extent and depth – Scenario 1, Year 2017, 20-yr discharge and 10-yr storm surge

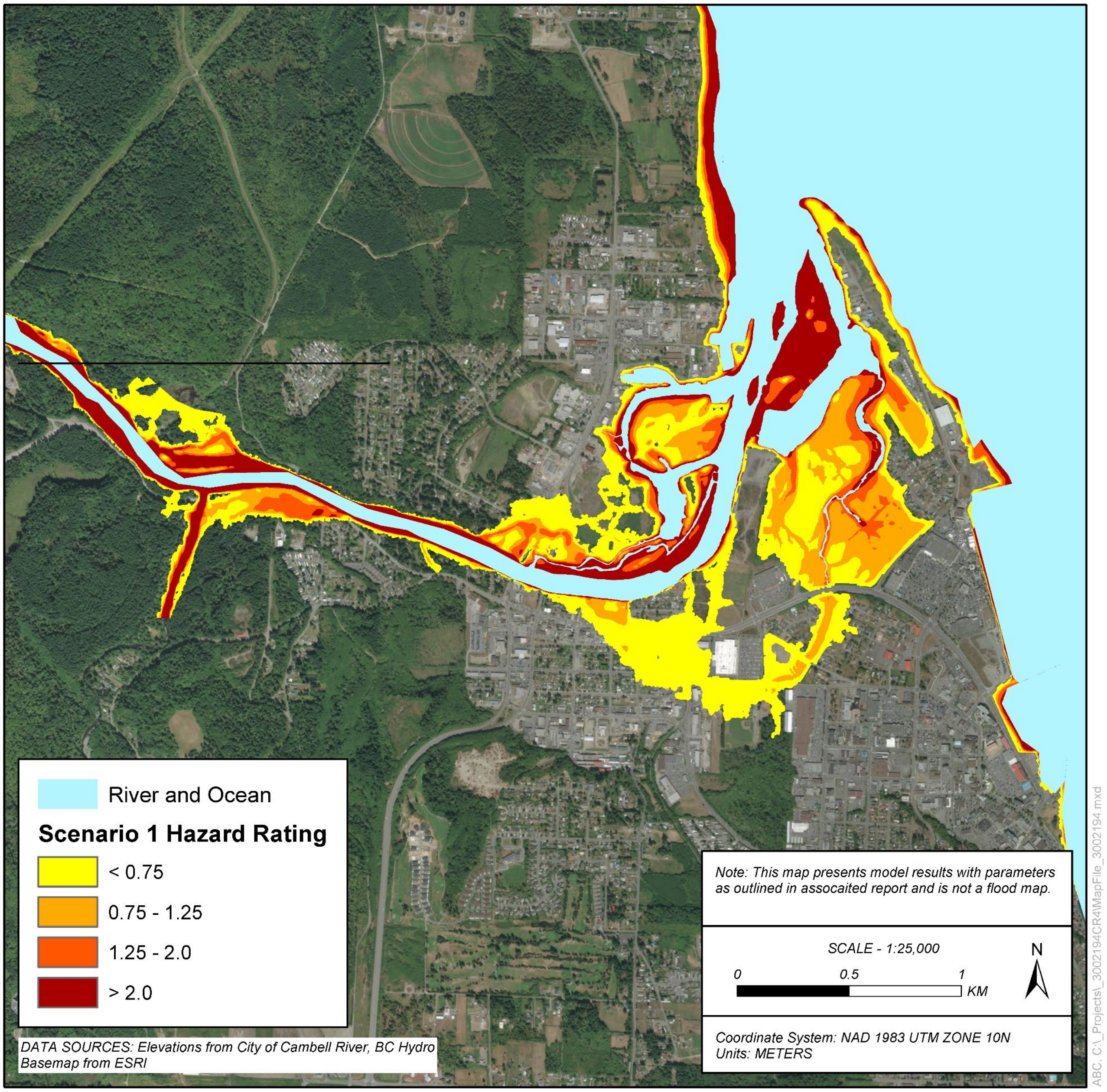
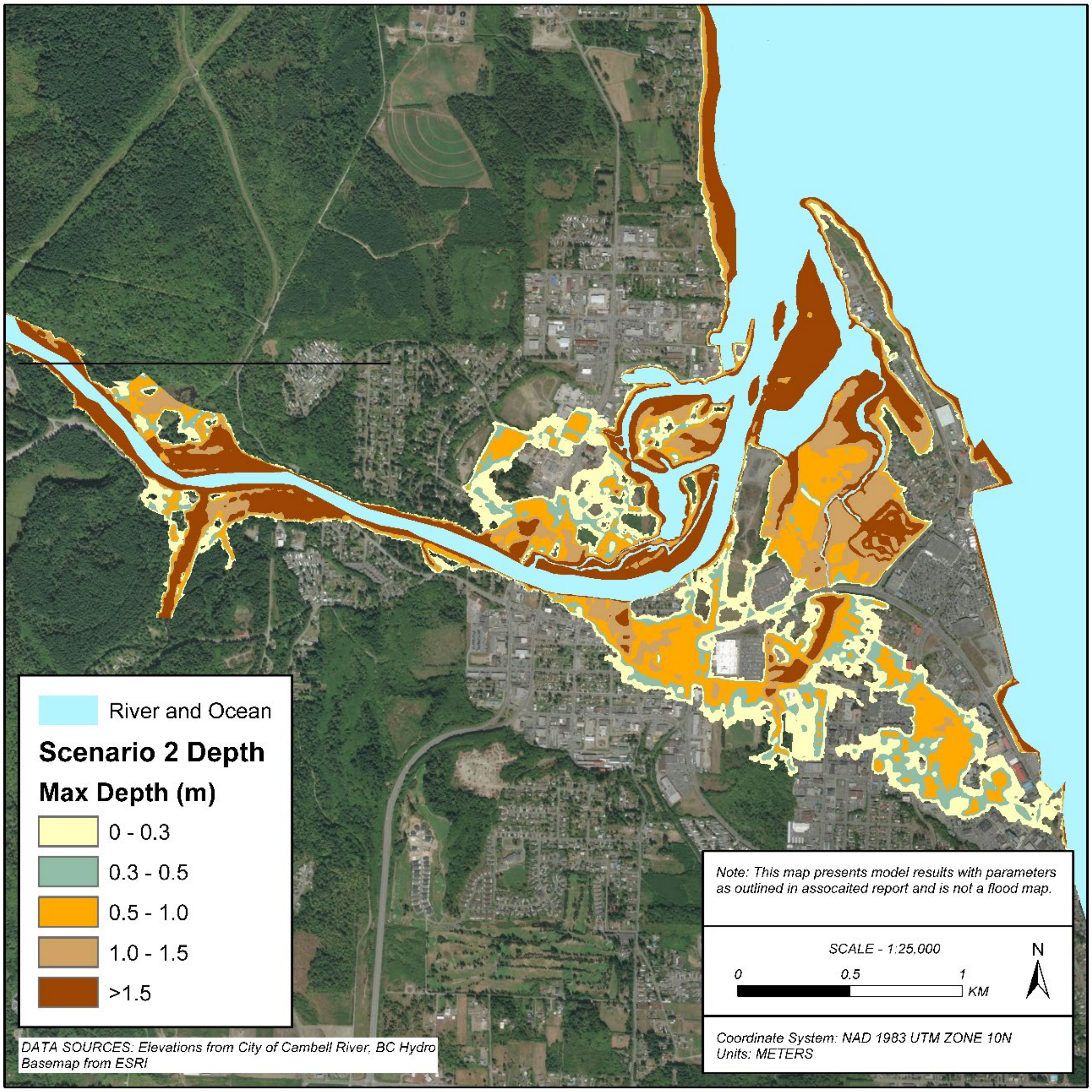


Figure 3-8: Maximum hazard rating – Scenario 1, Year 2017, 20-yr discharge and 10-yr storm surge



DATA SOURCES: Elevations from City of Cambell River, BC Hydro
Basemap from ESRI

Note: This map presents model results with parameters as outlined in assocaited report and is not a flood map.

Coordinate System: NAD 1983 UTM ZONE 10N
Units: METERS

Figure 3-9: Maximum flood extent and depth– Scenario 2, Year 2017, 200-yr discharge and 1-yr storm surge

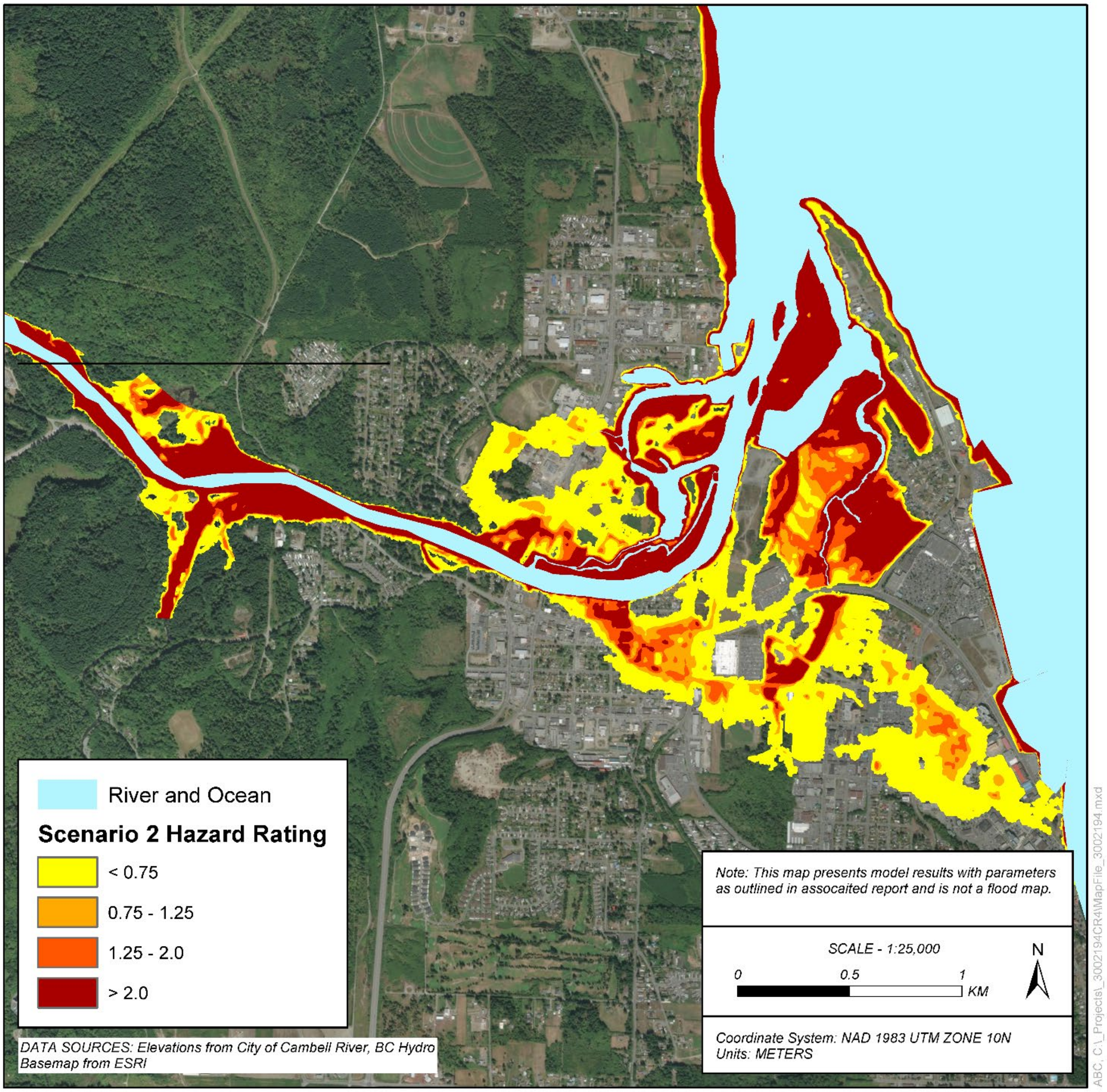


Figure 3-10: Maximum hazard rating – Scenario 2, Year 2017, 200-yr discharge and 1-yr storm surge

Figure 3-11 and **Figure 3-12** show the maximum flood extent and depth, and the maximum hazard rating for scenario 3 (Year 2050, 20-year discharge with 10-year storm surge) and scenario 5 (Year 2100, 20-year discharge with 10-year storm surge). The flood extents upstream of the Highway 19 Bridge do not vary much amongst the three time horizons suggesting limited tidal influence upstream of the bridge in these conditions. Downstream of the Highway 19 Bridge, however, the flood level and extent increases with increases in sea level rise. The water surface elevations at the Campbell River Lodge for scenario 3 and 5 were 3.6 m GD and 4.0 m GD, respectively.

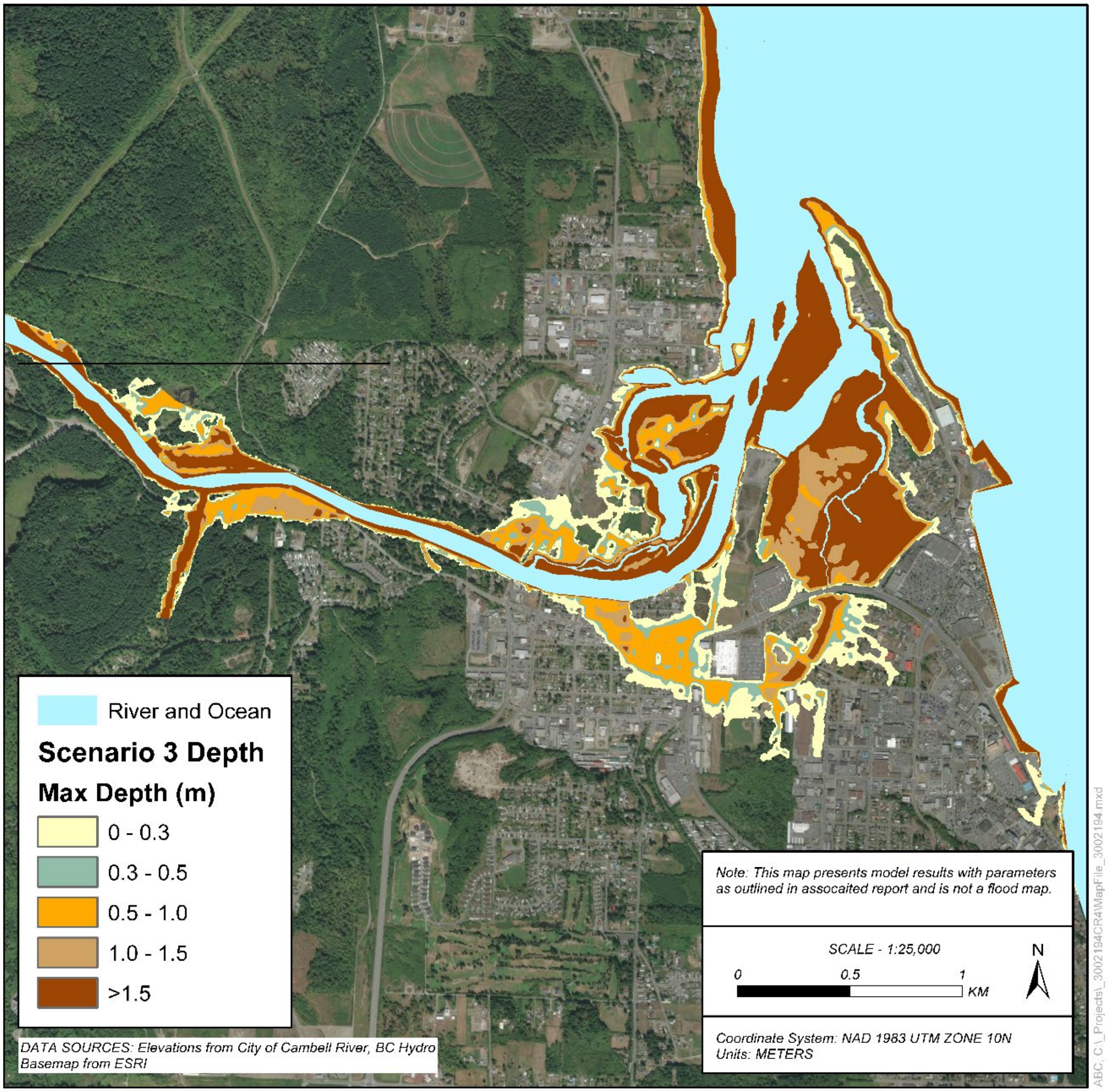


Figure 3-11: Maximum flood extent and depth – Scenario 3, Year 2050, 20-yr discharge and 10-yr storm surge

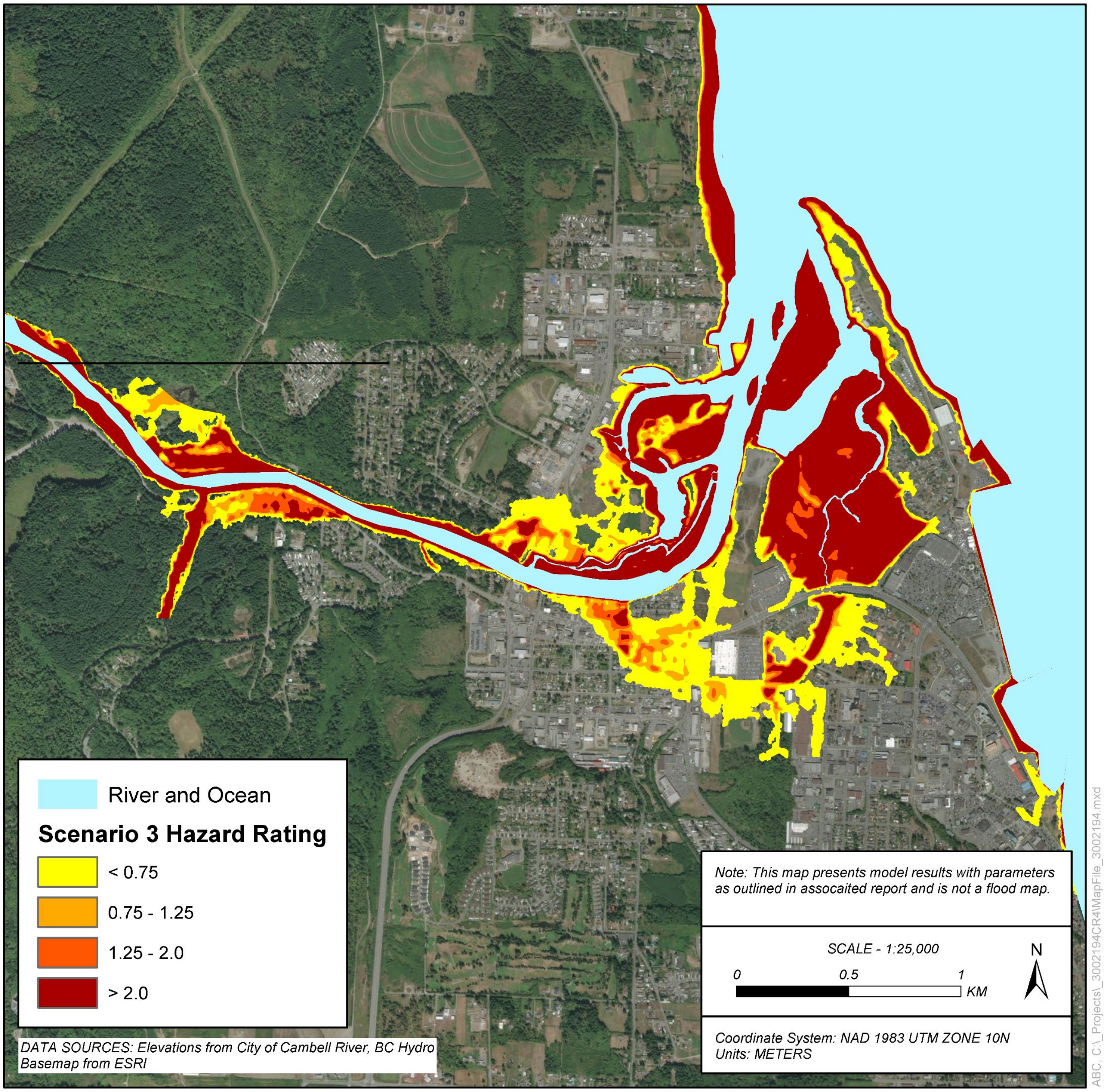


Figure 3-12: Maximum hazard rating – Scenario 3, Year 2050, 20-yr discharge and 10-yr storm surge

Figure 3-13, Figure 3-14, Figure 3-17 and **Figure 3-18** show the maximum flood extent and depth, and the maximum hazard rating for scenario 4 (Year 2050, 200-year discharge with 1-year storm surge) and scenario 6 (Year 2100, 200-year discharge with 1-year storm surge). Similar to the findings from the 20-year discharge simulations, the flood extents upstream of the Highway 19 Bridge do not vary much amongst the three time horizons suggesting limited tidal influence upstream of the bridge in these conditions. The flood level and extent increases with increases in sea level rise downstream of the Highway 19 Bridge. The water surface elevations at the Campbell River Lodge for scenario 4 and 6 were 3.8 m GD and 4.0 m GD, respectively.

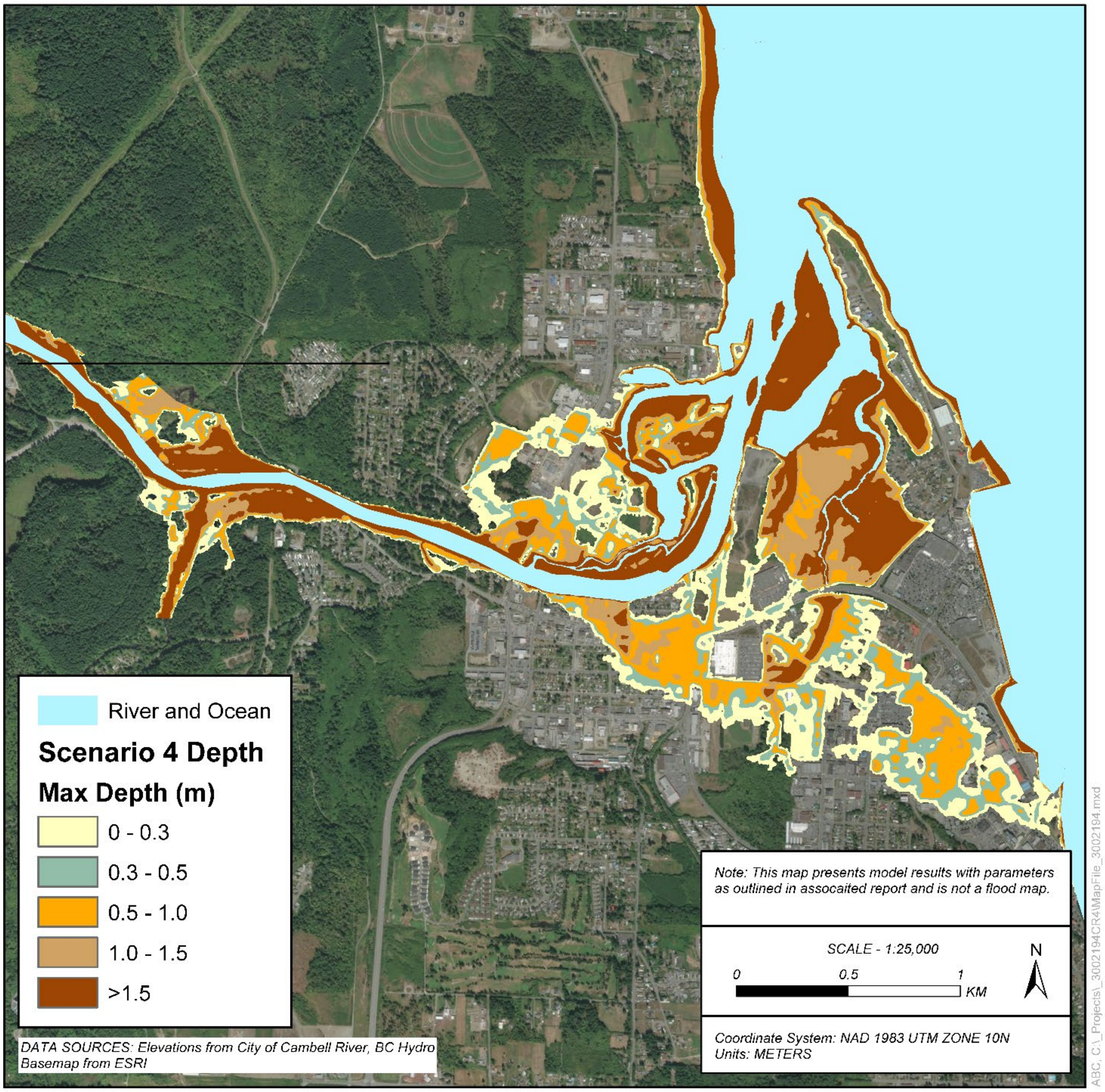


Figure 3-13: Maximum flood extent and depth – Scenario 4, Year 2050, 200-yr discharge and 1-yr storm surge

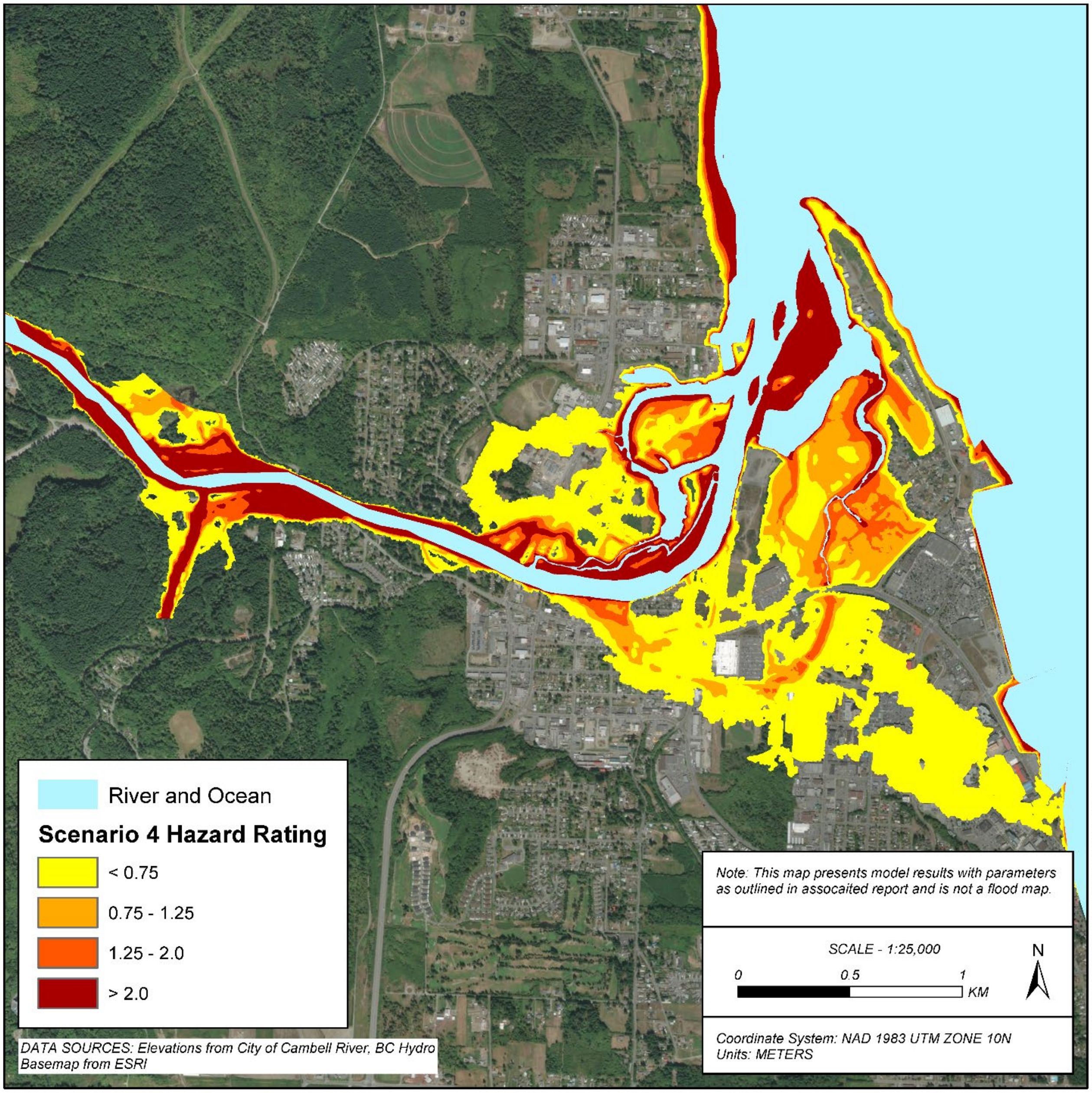


Figure 3-14: Maximum hazard rating – Scenario 4, Year 2050, 200-yr discharge and 1-yr storm surge

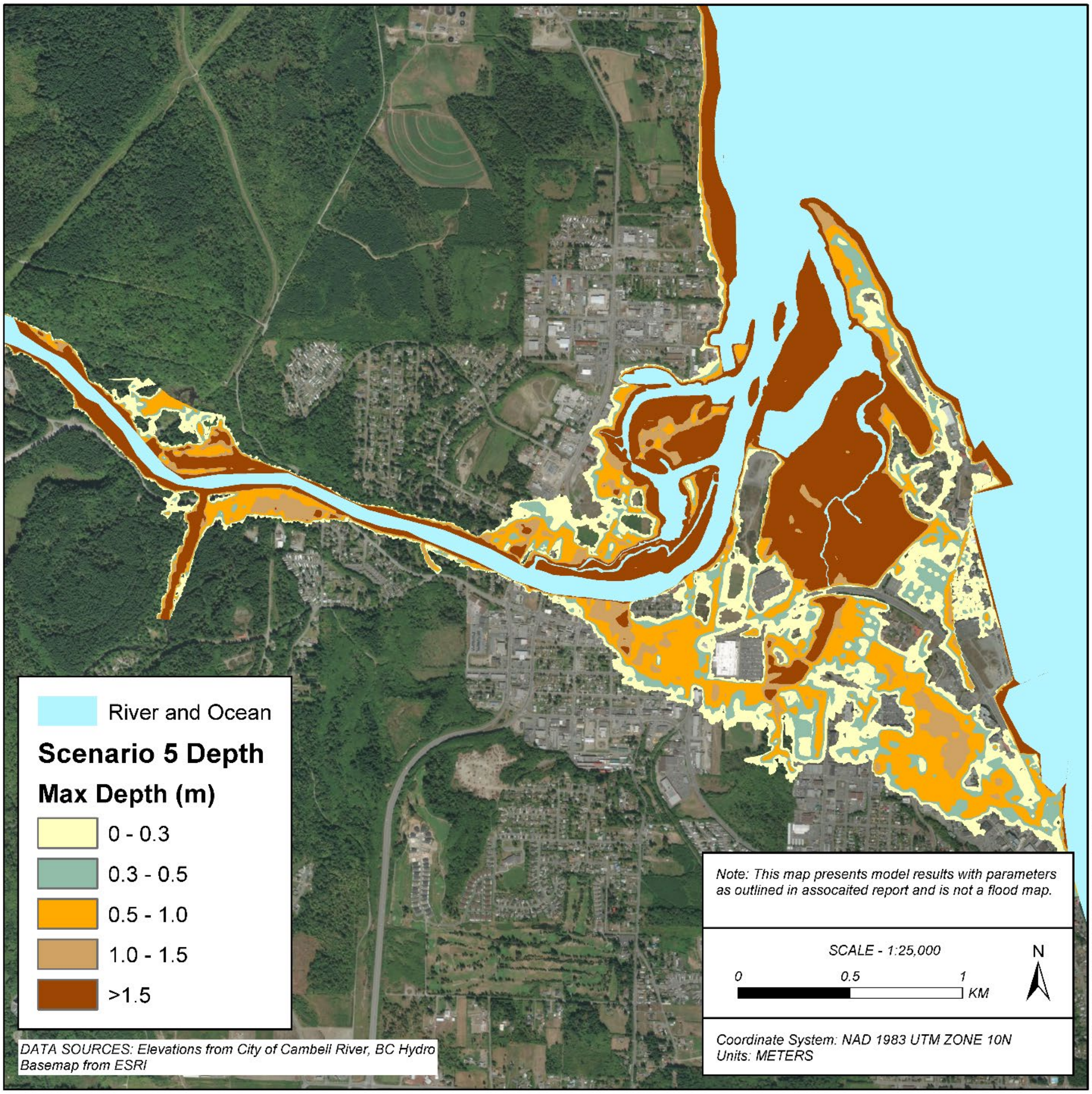


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Figure 3-15: Maximum flood extent and depth – Scenario 5, Year 2100, 20-yr discharge and 10-yr storm surge

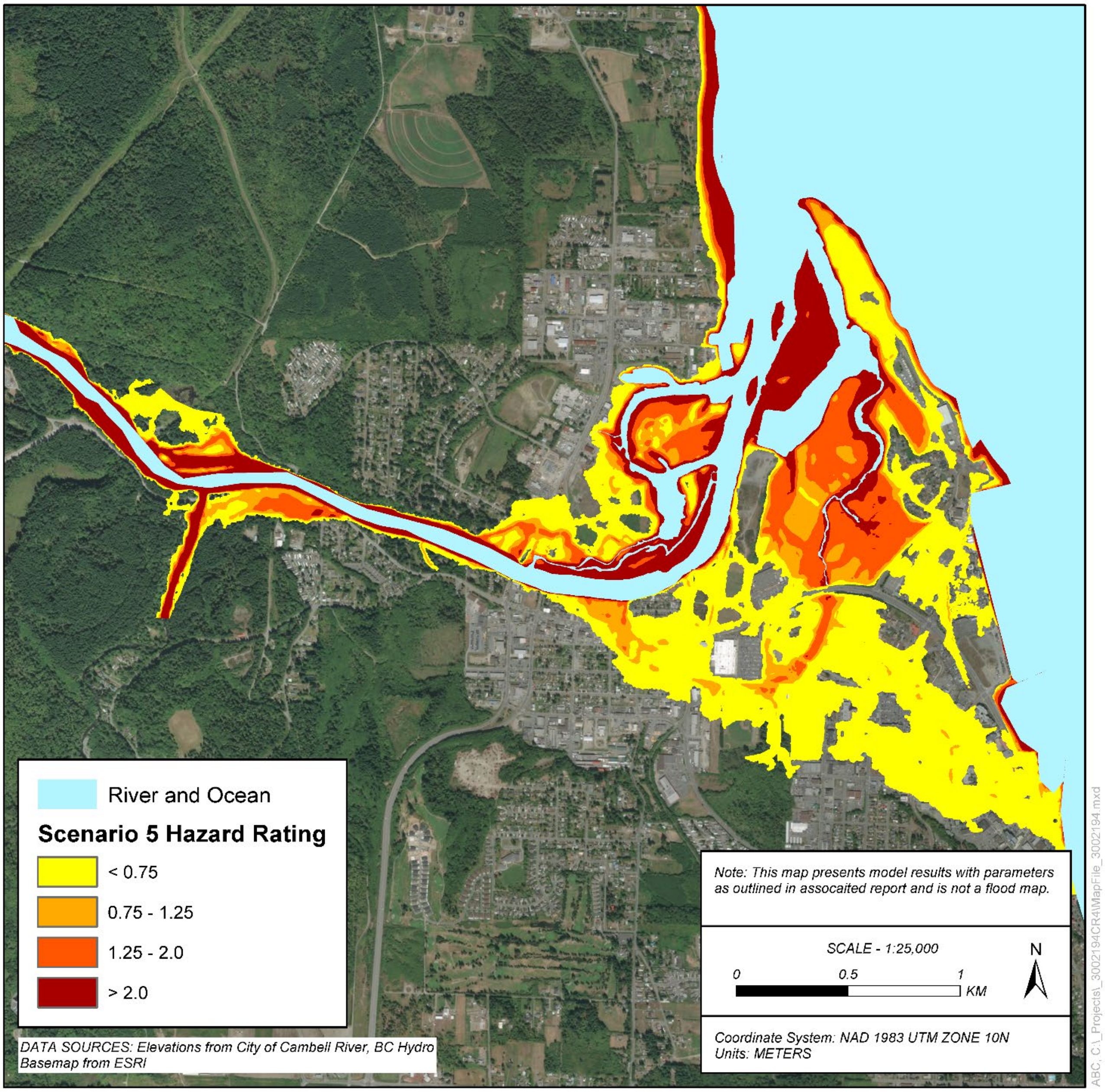


Figure 3-16: Maximum hazard rating – Scenario 5, Year 2100, 20-yr discharge and 10-yr storm surge

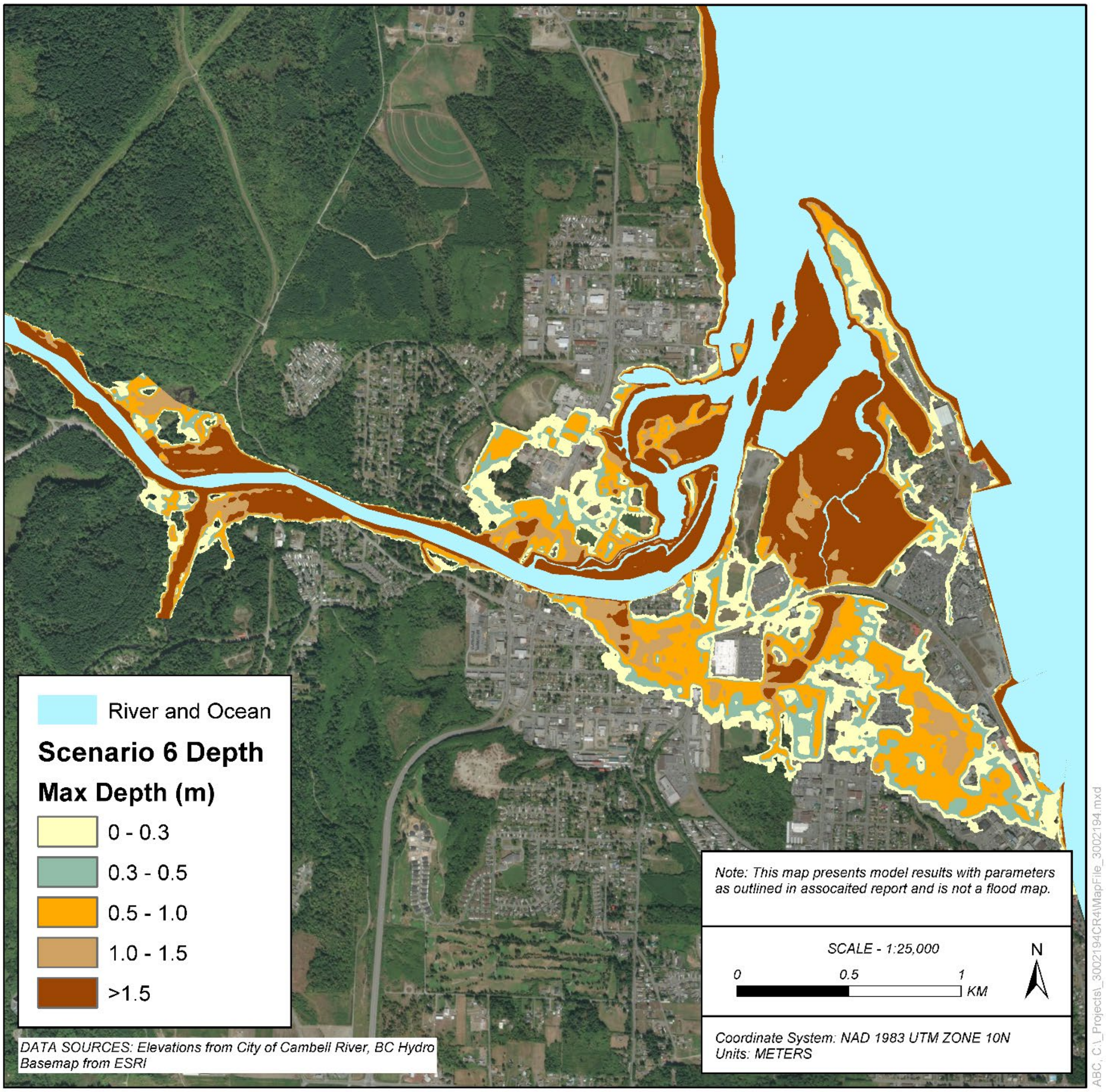


Figure 3-17: Maximum flood extent and depth – Scenario 6, Year 2100, 200-yr discharge and 1-yr storm surge

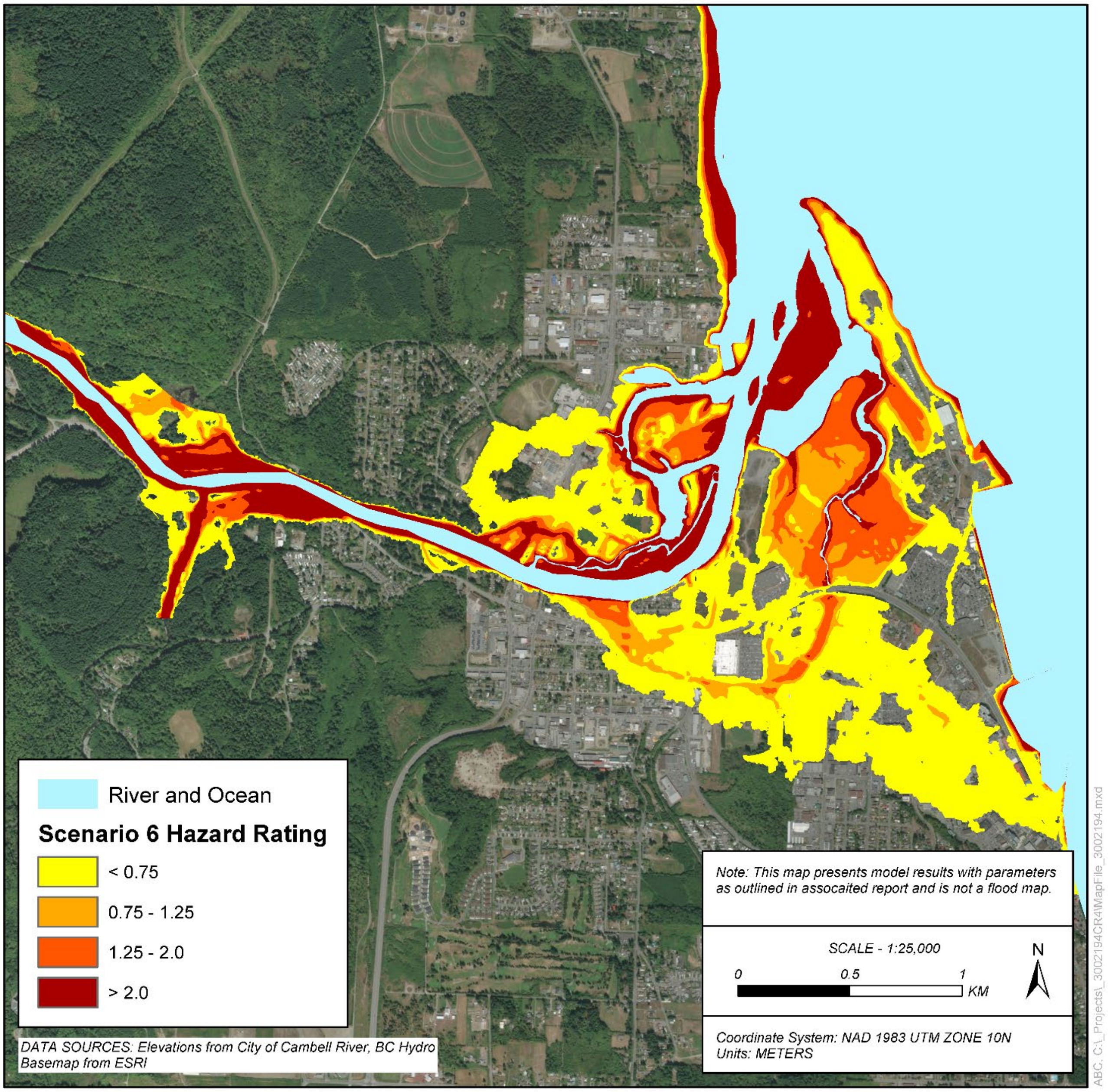


Figure 3-18: Maximum hazard rating – Scenario 6, Year 2100, 200-yr discharge and 1-yr storm surge

3.5 Modelling Limitations

The object of the modelling study is to evaluate the potential impacts and risks in the Campbell River estuary due to SLR. The model accuracy is limited by the input data and assumptions made. The input data accuracy and resolution is described in the modelling methodology and validation sections above. To have a refined understanding of flooding in the urban areas of this model, infrastructure including building footprints are required in addition to a Digital Elevation Model (DEM) of surface topography.

The model is a fixed bed model which means that erosion, deposition and channel or shoreline morphology changes are not modelled. A fixed bed model provides an understanding of the impact of the water interacting with the existing bed. However, in a real flood event, the floodwaters will likely cause morphological changes. A morphological assessment of potential changes in flow pathways and erosion in the Campbell River is required to properly understand the impact of the river flooding. Morphological changes could include significant channel migration due to erosion and deposition during high flows. As high river flows are usually attenuated upstream by the storage in the JHD reservoir, sediment can build up in the Campbell River system resulting in a potential for substantial sediment migration during high flows. Also, logs and other debris in the river could be mobilized by high flows, possibly creating downstream flow obstructions and changing flood patterns from the clearwater flood scenarios modelled.

Surface roughness in the model was set based on land use. While this presents a reasonable average picture, in reality, specific flow obstacles such as vegetation and building edges would affect local velocities at a fine scale. Flow velocities are likely overestimated in areas of mature vegetation and riparian areas.

Assumptions include no precipitation occurring during the modelled period within the model domain in order to focus upon the combined effects of SLR and river flows. Also, no stormwater conveyance is modelled. Depending on infrastructure configuration, stormwater systems have the potential to reduce flood levels by conveying floodwaters to ocean outlets or increase flood levels by backwatering due to SLR or storm surges. Groundwater can also have a significant impact on flood levels. High surface water levels can cause high water tables leading to groundwater seepage and significant impacts behind flood barriers, in basements and potential daylighting in low-lying areas. If the modelled events occurred during precipitation events, there could be higher flood levels due to direct precipitation and runoff, and there would be reduced capacity in stormwater systems for floodwater conveyance. Also, no wave effects such as overtopping are modelled. Large waves can overtop waterfront barriers and flood coastal areas. Stormwater drainage and elevation of coastal barriers are key components in determining the impact of wave effects on overall flood levels.

While the model accounts for climate change in terms of sea level rise (based upon the present planning curve as recommended by the BC government), and represents potential future flow conditions in terms of estimated sea levels and river discharges, it models current land use, surface cover and conveyance infrastructure. Significant changes to the built environment in Campbell River (such as the mitigative measures suggested in the report) will change floodwater patterns.

Finally, it is important to note that while sea level rise is directly included, potential climate change effects on peak flow rates have not been assessed. Estimating peak flows downstream of storage dams is a complex process that would require collaboration with the dam operator, and incorporation of potential changes in rainfall patterns from climate change. Such analysis is outside of the scope and schedule of this assignment.

4 VULNERABILITY ASSESSMENT

The main objective of this task is to identify City infrastructure assets vulnerable to sea level rise and located within the inundation zones.

4.1 Methodology

The maximum flood depth from each of the flooding scenarios was used to determine the receptors impacted by inundation. The spatial extent of inundation was compared to the receptors located within the inundation polygon and the impacted infrastructure inventoried and reported in Section 4.2 below. The inundation area was divided into two segments based on the 2017 Cowichan Valley Emergency Preparedness Workbook: one with a maximum water level less than 0.3 m, and one with a maximum water level greater than 0.3 m. This separation differentiates between areas which have the potential to be significantly impacted by floodwaters and areas where inundation is expected to be low consequence.

An analysis of water conveyance infrastructure within the zone of inundation was not completed as this information would not accurately represent the impact of flooding on conveyance infrastructure. Simply identifying the stormwater, sewer or drinking water conveyance infrastructure within the surficial inundation polygon does not account for the connectivity and capacity of the systems. In reality, flooding would exceed capacity of stormwater and potentially sewer systems, causing backwater and impacting a larger extent than the surficial flooding polygon. Pressurized flow in these systems could also cause surcharging upstream or downstream of the location of the inundation polygon. Therefore, the inundation polygon approach will not provide an accurate representation of the effect of flooding due to sea level rise on storm, sewer or water systems. A more detailed model which accounts for system connectivity and capacity is required.

4.2 Results

The results are summarized in the following tables and graphs. **Table 4-1**, **Table 4-2**, and **Table 4-3** show the receptors, land zones and vegetated areas affected by inundation respectively.

Table 4-1: Receptors Affected by Inundation

Flood Scenario*	Water Depth (m)	Area (ha)	Fire hydrants (#)	Parks (ha)	Fibre Optic (km)	Population (#)	Dwellings (#)	Roads (km)
1	0-0.3	36	6	10	0.00	70	40	2.6
	>0.3	1025	26	45	0.00	370	190	6.2
2	0-0.3	67	26	13	0.17	240	100	6.1
	>0.3	1073	50	52	0.35	520	250	11.8
3	0-0.3	45	18	10	0.00	110	50	3.9
	>0.3	1035	26	48	0.00	400	210	7.2
4	0-0.3	67	29	12	0.15	260	110	6.2
	>0.3	1080	50	55	0.38	530	260	12.2
5	0-0.3	68	38	9	0.12	200	70	5.7
	>0.3	1106	72	56	0.50	490	210	16.1
6	0-0.3	70	37	12	0.08	310	130	6.7
	>0.3	1107	66	58	0.49	640	300	15.2

* Flood Scenario Summary
1. SLR = 0.17 m, 20-yr River Discharge, 10-yr Surge
2. SLR = 0.17 m, 200-yr River Discharge, 1-yr Surge
3. SLR = 0.5 m, 20-yr River Discharge, 10-yr Surge
4. SLR = 0.5 m, 200-yr River Discharge, 1-yr Surge
5. SLR = 1.0 m, 20-yr River Discharge, 10-yr Surge
6. SLR = 1.0 m, 200-yr River Discharge, 1-yr Surge

Table 4-2: Vegetated Areas Affected by Inundation

Flood Scenario	Water Depth (m)	Cobble shore (ha)	Forest (ha)	Marsh (ha)	Mudflat (ha)	Riparian (ha)	Swamp (ha)	Terrrestrial-herbacious (ha)
1	0-0.3	0.1	1.0	0.3		1.8		2.7
	>0.3	7.1	8.5	34.6	38.9	26.8	2.1	4.8
2	0-0.3	0.1	1.5	0.5		2.2		3.2
	>0.3	7.0	7.8	34.4	38.9	26.3	2.1	4.5
3	0-0.3		0.3	0.3		1.4		2.1
	>0.3	7.2	9.2	34.7	38.9	27.8	2.1	6.3
4	0-0.3		0.6	0.3		1.9		2.6
	>0.3	7.2	8.9	34.6	38.9	27.3	2.1	5.8
5	0-0.3		0.1	0.1		0.8		1.3
	>0.3	7.2	9.5	34.8	38.9	29.2	2.1	8.1
6	0-0.3		0.1	0.2		1.1		1.8
	>0.3	7.2	9.5	34.8	38.9	28.7	2.1	7.5

Footnote: Vegetated areas are derived from shoreline mapping provided by the City of Campbell River. Final polygons denoting cobble shore, forest, marsh, mudflat, riparian, swamp, and terrestrial-herbaceous areas were used. Documentation of areas is provided in the Campbell River Estuary Vegetation Communities Report by Greenways Land Trust in November 2017. These values are only based on a desktop analysis, a full biological assessment should be undertaken to thoroughly understand the ecological impact of flooding.

Table 4-3: Land Zones Affected by Inundation

Flood Scenario	Water Depth (m)	Commercial (ha)	Residential (ha)	Industrial (ha)	Unzoned (ha)	Rural (ha)
1	0-0.3	9.3	5.3	0.9	4.7	1.9
	>0.3	81.8	11.6	0.9	49.7	7.3
2	0-0.3	22.3	7.8	1.2	10.9	2.3
	>0.3	101.7	14.6	1.6	55.6	10.9
3	0-0.3	12.2	5.7	1.0	8.2	1.9
	>0.3	84.2	12.4	1.1	52.0	7.4
4	0-0.3	23.1	7.8	1.2	11.0	2.3
	>0.3	103.3	15.1	1.6	56.9	11.0
5	0-0.3	23.4	6.9	1.2	17.1	4.3
	>0.3	114.6	15.0	1.5	65.9	11.7
6	0-0.3	22.8	8.3	1.2	14.5	2.3
	>0.3	114.0	16.5	1.8	62.0	11.1

Graphs of inundation by key receptors for each flood scenario are shown in **Figure 4-1**, **Figure 4-2**, **Figure 4-3** and **Figure 4-4**. Numbers are the scenarios as referenced in **Table 3-2**.

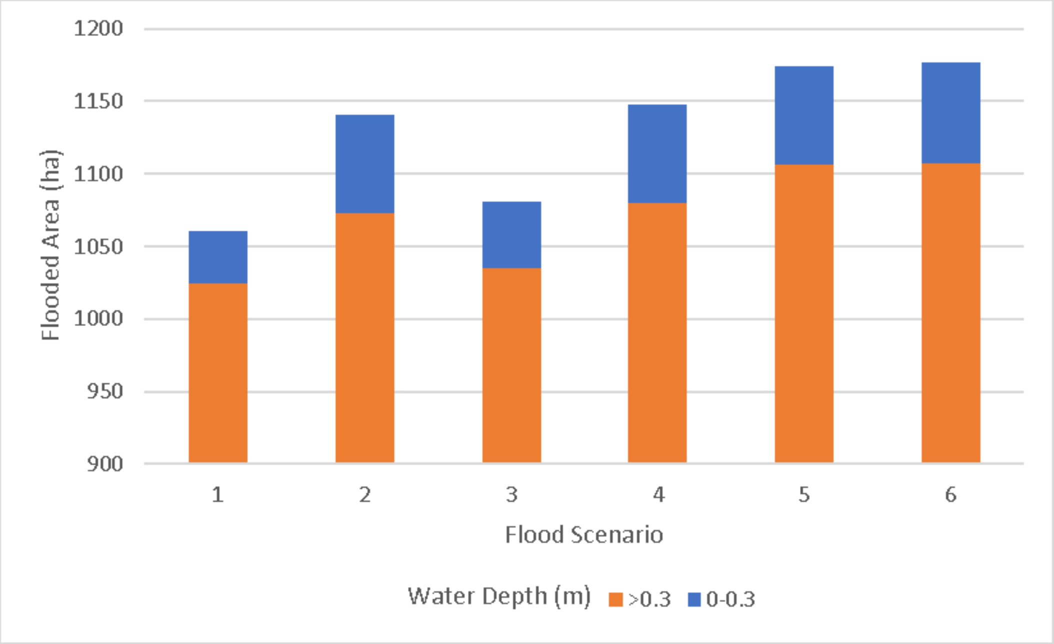


Figure 4-1: Flooded Area in Each Flood Scenario

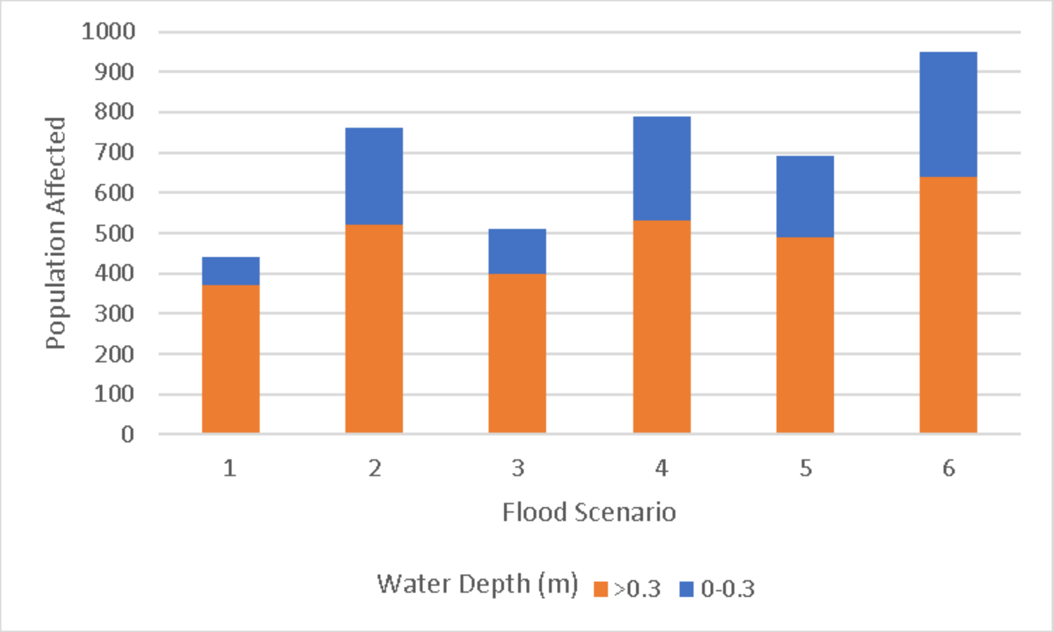


Figure 4-2: Population Affected in Each Flood Scenario

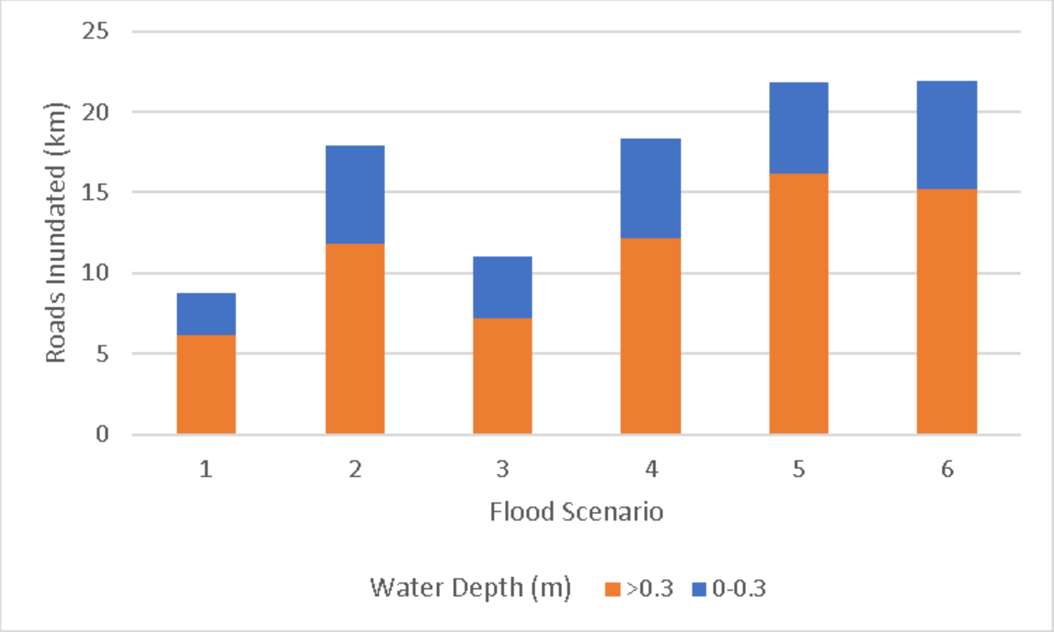


Figure 4-3: Roads Inundated in Each Flood Scenario

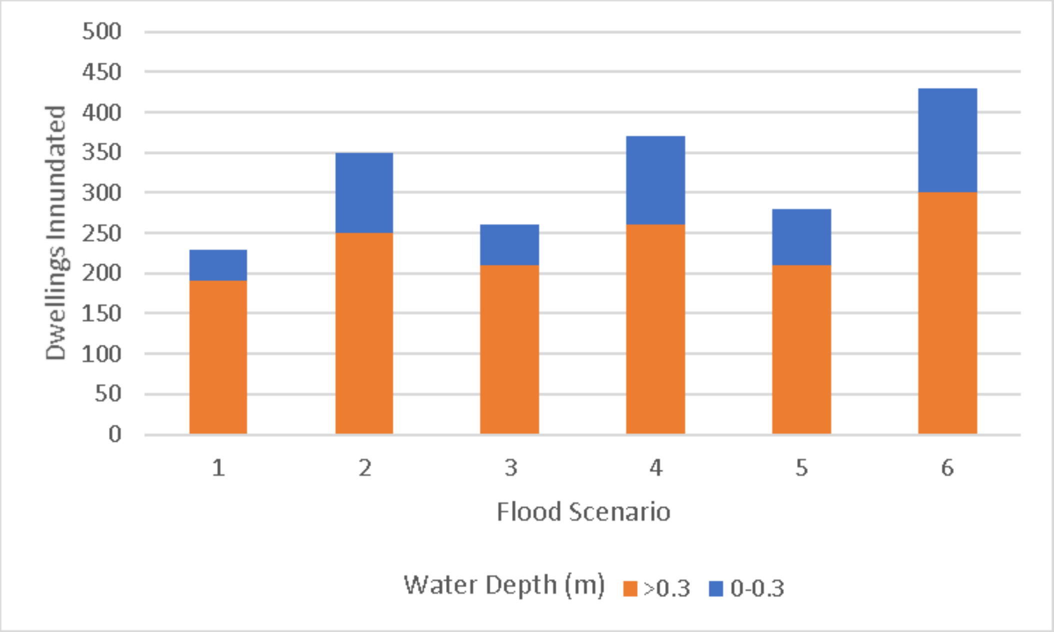


Figure 4-4: Dwellings Inundated in Each Flood Scenario

4.3 Limitations

This analysis is limited to an inventory of receptors located within the inundation areas for each scenario. The receptor inventory is based on data provided by the City of Campbell River and publicly available Canadian census data. The receptor data was not verified through aerial or ground surveys. In addition to limitations in the accuracy of the analysis, the scope was very limited based on available scope and effort for this assignment. For population and dwelling counts, a ratio based on the portion of the census blocks located within the inundated area was used to scale counts for the whole census block. This is an estimation which does not necessarily accurately reflect the inundated infrastructure. **Section 4.4** recommends future analysis which incorporates an expanded list of receptors, a refined consideration of inundation, consideration of vulnerability and resilience, expanded impact estimation and the development of a consequence rating.

4.4 Recommended Future Analysis

A robust analysis of exposure, vulnerability and risk is possible as outlined below. The depth, velocity and flooding duration results from the 2D model provide the necessary modelling inputs for a detailed analysis of exposure, vulnerability and risk. A recommended analysis procedure is as follows.

1. **Expand list of receptors**. Include public safety assets such as: police; fire; ambulance; search and rescue; and hospitals. Include any emergency access or egress routes, shelters or coordination centres which have been planned. Expand critical infrastructure list to include datasets not currently available through the municipal data inventory including: BC Hydro substations and transmission grids; cell phone towers; water and sewage treatment plants; schools; and health centres. Expand transportation infrastructure list to include: public transit routes; railways; highways; bridges; key port and ferry infrastructure; and airports. Include detailed information about buildings, specifically: type of building; zoning; construction; and presence of basement. Include more environmental assets including ecological sites and habitat zones. Include sites potentially threatening to the environment including contaminated sites and storage areas of potentially toxic materials. Include cultural assets, such as, parks, beaches, monuments, burial grounds, archeological sites, paths and recreational wharfs. Consultation with community stakeholders is a key stage to ensure the list of receptors is comprehensive.

2. **Refine consideration of inundation.** Rather than only considering occurrence of inundation, also consider flood depth, flood water velocity and duration of inundation. A comparative classification matrix can be used to account for these factors.

3. **Expanded impact estimation.** Based on the list of receptors, impacts of inundation should be considered. The scope of impacts considered should include: human; economic; environmental; and political and social. Human impacts include the number of people affected, including by death, severe injury or illness, displacement due to loss of home or livelihoods. Economic impacts include the costs of the damage, the costs of the reparation and restoration, the costs of emergency measures and the costs of long term recovery (costs of disruption of economic

activities, unemployment, indirect social costs such as those for the restoration of education and health systems and loss of use of the port). Environmental impacts include the loss of or damage to high value habitat areas, ecosystems and protected species, as well as general environmental pollution. The costs of environmental recovery are in most cases seen as part of the economic impact. Political and social impact include political implications of a disaster, social psychological impact, disruption of daily life, and violation of peace and rule of law. It could also include impact on development gains, (in)equality and social cohesion, as a separate "value to protect". A combination of quantitative and semi-qualitative methods can be used for the impact estimation depending on data availability and level of resources. Consequence estimate software can be used to facilitate impact estimation.

4. **Vulnerability and resilience consideration.** As part of a refinement of understanding the impact, a consideration of vulnerability and resilience should be incorporated. Natural Resources Canada (NRCan) has applied research about the social, economic and health variables that are known to influence capacities for response and recovery to the Canadian context (per comm, Murray Journeay May 11, 2018). NRCan has developed a neighbourhood level model incorporating these factors to reflect intrinsic capacities for response and recovery. The vulnerability and resilience of environmental and cultural assets should also be considered as these types of assets could be impacted more by increases in typical water levels and nuisance flooding rather than extreme flood events. Environmental resilience and therefore impact of an extreme flood event may also be affected by changes to depth, duration, and frequency of inundation, wave action, and potentially changes to sediment transport regimes and sediment texture.

5. **Developing consequence rating.** To facilitate interpretation of results, receptors should be amalgamated into consequence ratings. Moving past a list of impacted receptors to a consequence rating which incorporates: likely effect on receptors due to inundation; the vulnerability and resilience of receptors; the economic value of lost receptors; societal value of impact to people; social and cultural values impacted by effects on receptors. This consequence rating (which can be done based on an areal unit of choice – census dissemination block, measurement unit, etc.) allows for interpretation of impact and identification of priorities for risk mitigation based on community values. Risk mitigation should include not only target physical objectives for protection from floodwaters, but also objectives for adaptability and resilience improvements. The development of the consequence rating requires significant community stakeholder input.

5 MITIGATIVE MEASURES

An effective mitigation strategy evaluates a variety of options to develop a protection strategy appropriate for the estuary area. This section of the report introduces general mitigation strategies and then discusses options specific for the flooding modelled in this study.

5.1 General Options

The potential mitigation approaches include the broad categories of accommodate, protect, retreat, and a combination of the above. These approaches are further explained below and depicted in Figure 5-1:

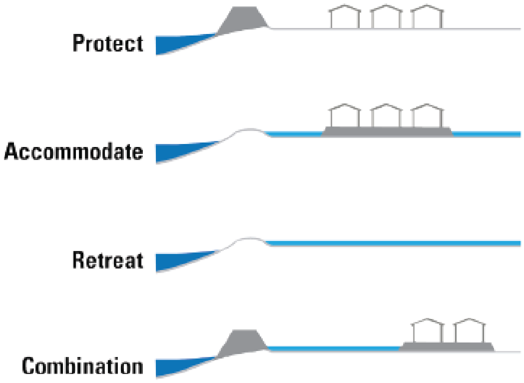
- **Protect:** build or raise structures to keep floodwaters out and protect people, property, and infrastructure. Examples: dykes, sea walls, offshore reefs to attenuate wave energy. Vegetation such as wetlands can also buffer the impacts of storm surge. It is also possible to reclaim land from the sea through dredging, diking, fill, etc.

- **Accommodate:** make changes to buildings, infrastructure and human activities so that when flooding occurs harmful impacts are minimized. Examples: move important assets and building electrical and mechanical services to higher floors and allow the ground floor to flood; design public spaces to function as waterways when flooded; and land filling to raise development sites.

- **Retreat:** plan for the eventual relocation of people and buildings currently in the floodplain. Examples: purchase houses in the floodplain through voluntary or mandatory programs; relocate key infrastructure outside the area at risk. Retreat can also include actions to avoid coastal flooding hazards and risks by not locating new development in flood-prone areas. Example: designating "no build" areas in local government plans.

- **Combination:** refers to a mix of two or three of the options.

Figure 5-1: Adaptation Options



To enact the above adaptation approaches, interventions are required. Interventions can include structural and physical measures, social measures and institutional interventions. These types of interventions are generally described below.

Intervention type[7]		**Example**
Structural/ physical	Engineering	Dykes, sea dams and coastal protection structures; groins and breakwaters; water storage and water pumps; improved drainage; beach nourishment; erosion protection (rip-rap/dolos/etc.); dune building; barrier islands; diversion channels; land reclamation; etc.
	Built environment	Building codes; transport and road infrastructure adaptation; raised home and building construction; permanent resistance (dry flood-proofing); temporary resistance (dry flood-proofing); resilience (wet flood-proofing); etc.
	Ecosystem-based	Green Shores; natural erosion control (e.g., wood on beach, grasses); ecological restoration (including wetland and floodplain conservation and restoration); etc.
Social	Educational	Awareness raising and integrating into education; knowledge-sharing and learning platforms; communication through media; etc.
	Informational	Ongoing hazard and vulnerability mapping; early warning and response systems; systematic monitoring and remote sensing; etc.
	Behavioral	Household preparation and evacuation planning; managed retreat; soil and water conservation; changing livestock practices; changing cropping practices, patterns, types, and planting dates; etc.
Institutional	Economic	Financial incentives including taxes and subsidies; insurance incentives; payments for ecosystem services; cash transfers; etc.
	Laws and regulations	Changes in land use designations, development permit areas, and zoning; new and revised development and subdivision servicing standards; new easements for upgraded dykes; new setbacks from high risk areas; laws to support disaster risk reduction; bylaws to encourage insurance purchasing; acquisition of undeveloped & developed land; relocation of property & infrastructure; etc.

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[7] Adapted from page 845 of Noble, I.R., S. Huq, Y.A. Anokhin, J. Carmin, D. Goudou, F.P. Lansigan, B. Osman-Elasha, and A. Villamizar, 2014: Adaptation needs and options. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

	Government policies and programs	National and regional adaptation plans; disaster planning and preparedness; etc.

5.2 Specific Options

Through mitigation measures, the potential consequences of flooding in Campbell River can be reduced. This section outlines high-level suggestions specific to flooding in Campbell River. These suggestions developed through examination of the model results and knowledge from local individuals with some understanding of past flooding in the area. These mitigations have not been modelled or designed, even to a conceptual level. They are suggestions to facilitate conversation about site specific constraints and requirements, many of which are expected to significantly alter the mitigation strategy. Mitigations are targeted to protect vulnerable, developed areas with extensive infrastructure, but a thorough evaluation of community protection priorities should be completed to identify priority areas to protect from floods. Model simulation results and local topography identify a few critical areas where flood mitigation strategies could be employed (**Figure 5-2**).

The specific options listed below are in no particular order with respect to priority. Options A and B are both located at sources of flood waters that reach the downtown area and should be considered as a priority for those areas, but for residents and businesses on the north side of the estuary option I is of utmost interest. And improved drainage in the downtown area (option E) is perhaps the quickest means to reduce the risk of deep water flooding in the downtown area. It is not within the mandate of this report to provide any commentary on priority as this becomes a community discussion.

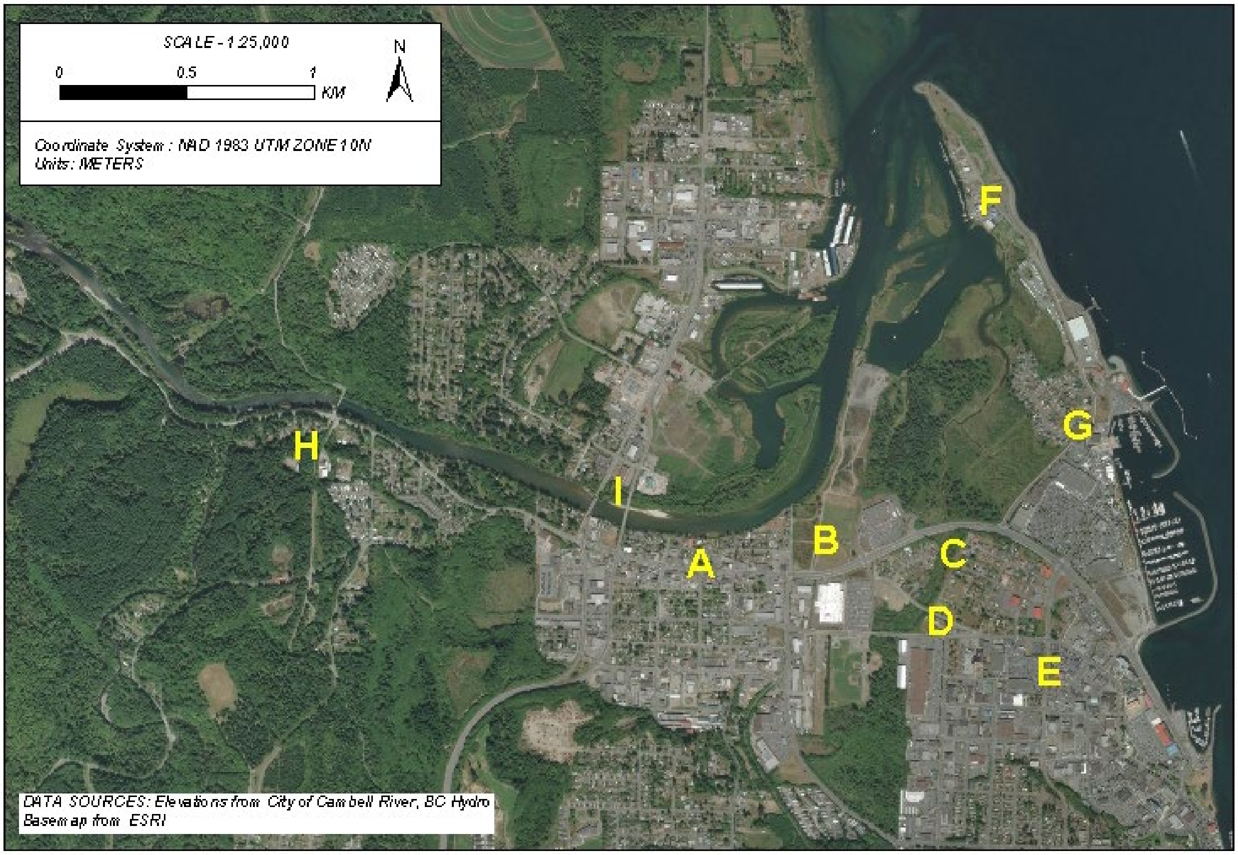

Figure 5-2: Key potential mitigation locations

A Campbell River Lodge

The area at and near Campbell River Lodge is shown in the model as an inundation location, confirming observations of past flooding at this location. The Campbell River Lodge is located at a relatively low elevation location along the south bank of the Campbell River. When river discharge is high, inundation occurs at the lodge, with flood waters leaving the river at this location and impacting a significant area to the south and west of the lodge eventually connecting to the greenway along Nunns Creek.

Construction of a river dike along the bank at this location could reduce the potential for overflows and related flooding. However, there are several considerations associated with an engineered dike in this location including: requirements for a significant right of way; impacts on fish habitat of associated erosion protection; possible effects on flood levels or erosion due to channel constriction and deflection associated with protection works; internal drainage considerations behind the diked barrier; significant construction costs; and ongoing maintenance costs. The river dike would need to tie into high ground (above river flood design levels) at the upstream end and, would need to tie-in to relatively high ground at the downstream end to be at least partially effective against coastal flooding. The highway bridge where it crosses the Campbell River may act as a suitable upstream tie-in, but this would need detailed analyses. The apparent higher land to the east of the lodge may be suitable as a downstream tie-in.

An analysis of the feasibility to construct a new dike is required to determine the footprint of the dike, but potential alignments include along the riverbank, possibly adding a continuation of the Myrt Thompson Trail or underlying Highway 19A. The additional analysis would determine the alignment, elevation and feasibility of this dike.

An alternative adaptation concept could be to raise the overall land surface elevation in this area by use of fill material. Obviously this may be disruptive to some existing properties, and may not prevent all overflows. However, it could significantly reduce the flow rate and volume of water entering the downstream areas and possibly reduce the impacts. From a regulatory perspective, this concept could be easier to implement than a flood protection dike by avoiding the regulatory requirements triggered by the in-stream component of a formal dike while largely mitigating flood impacts. (Further modeling of this area including and stormwater drainage is recommended to confirm the location, scale and benefits of this potential mitigation measure).

Additionally, the City should consider floodplain bylaw updates for this area that would put restrictions on new construction, elevate FCL levels where new construction is allowed, and create the groundwork for a managed retreat in the long-term from the riverbank area.

B Southern Portion of Myrt Thompson Trail

Modelling shows inundation along the southern portion of Myrt Thompson Trail between the two fields west of the Home Depot. This water then connects to floodwaters from the Campbell River Lodge area, and flows into Nunns Creek and the downtown area.

One option to reduce overflows in this location could be to raise the lowest elevation areas by landfilling. While the landfilling would include the trail, the landfill would need to be much wider so that it does not act as, nor need to be designed as a dike. As suggested above for the Campbell River Lodge site, further detailed modeling would be required to demonstrate any flood mitigation benefits.

An extension of the potential dike at the Campbell River Lodge would reduce flooding at this site. Further study of the required elevation and extent of this potential mitigation is required. However, the extension of the dike would have many of the constraints outlined in Section A above.

C Culverts under Island Highway

When water levels in the estuary and ocean are high due to high tides and expected SLR, Nunns Creek is inundated. Nunns Creek and the surrounding low-lying areas fill with water, and modelling shows that this water flows through low-elevation streets to the downtown area. The culverts which carry Nunns Creek under highway 19A are currently open to flow both up and downstream. Eliminating upstream flow through installation of sea dams (flap gates) on the culverts has the potential to reduce inundation from the Nunns Creek area to downtown (However, we note that such features could have adverse environmental impacts that offset their net benefit). Further study of the connectivity of the Creek and Ocean and subsequent definition of the optimal operation of the sea dams is required.

D First Nations Land - Quatell Ave

The largest direct link between Nunns Creek and the downtown area occurs along the Creek's eastern bank adjacent to Quatell Ave. While installation of some works at A, B and C may reduce the flooding in Nunns Creek, further analysis is required to confirm this. If further mitigation is required, a low berm could be built along the eastern bank of Nunns Creek along Quatell Ave. This berm would help to confine flow to Nunns Creek and reduce inundation over Quatell Ave through to downtown. Modelling of the effect of mitigations A through C is required to determine the need and extent of a potential berm along Quatell Ave. Significant challenges would be associated with development and construction of this option. It may likely not be feasible to eliminate flooding in the immediate vicinity of Nunns Creek through structural means alone. Retreat, rezoning and other land use mitigation options should be considered in parallel.

E Downtown Area

Floodwaters reach the downtown area via pathways through the Campbell River Lodge low area and from ocean inundation along Nunns Creek. While mitigations at location A and B will likely reduce the overall flooding in the downtown area (as indicated in the flood extents earlier in this report), drainage in the downtown area is key in reducing flood levels. A functioning, adequately sized stormwater system can convey floodwater away from the built environment to outlets. The stormwater system must be adequately sized to convey potential flows, clean to function as intended, and resilient to sea level rise. Resiliency occurs through management of the elevation of conduits and outlets and installation of backwater valves to minimize inundation through the stormwater system. An analysis of the capacity, resiliency and maintenance practices of the stormwater system is required to establish its potential to reduce flood levels in the downtown area.

It has been assumed in this analysis that properly designed coastal defenses are maintained to prevent wave action during storms from contributing to flooding in the downtown area.

F Seaplane terminal

The various seaplane terminals at the northern end of the spit in the mouth of the Campbell River are impacted by SLR and high river discharges. Due to narrowness of the spit and the connectivity required between the sea and the land for floatplane operations diking and most forms of protection are infeasible. However, accommodation of expected high water levels would most likely be possible in this area. Accommodations could include: flexibility in elevation of floating dock infrastructure; changing or elevating hazardous materials ie fuel storage; raising buildings; raising roadways, eliminating or waterproofing building basements; adapting utility locations on the first floors of buildings; and changing usage of first floors of buildings. Further analysis of model results to determine recommended accommodation elevations and operational constraints is required.

G First Nations land east of estuary.

The First Nations residential area east of the estuary off of Spit Road along Henderson Ave and Loughborough Drive is at risk of some peripheral flooding from Nunns Creek. Based on model results, this area does not experience significant inundation – there is some peripheral inundation of the area along the back of houses along the southwest side of Loughborough Drive. This inundation can be mitigated and managed through temporary flood measures including sand bagging, and temporary diking during flood events. Further analysis of the frequency of expected events should occur to ensure the feasibility of this mitigation. Also, SLR related zoning should be considered for this area which would facilitate long term adaptation of infrastructure to occasional flooding.

Inundation in this area also occurs at the intersection of Loughborough Drive and Spit Road with floodwaters crossing Spit Road to the marina and boatyards adjacent to the ocean. In addition to the impact of the floodwaters on the infrastructure on the east side of Spit Road, floodwater covering Spit Road could act as a barrier between emergency services and the population in the residential area to the north of this intersection. Mitigation options such as raising the road and/or conveying the water under the Spit Road to the ocean via a culvert should be analyzed further.

H Quinsam River and Campbell River south side at Detweiler Road

Flooding impacting infrastructure also occurs in the developments near Detweiler Road and Highway 28 (Campbell River Road). Flooding occurs both over the riverbank and in Quinsam River which runs north-south and intersects the south bank of the Campbell River. The impacted area is limited to the low-lying area around the river – a low density residential area containing 15-20 homes. An engineered protection in this area have to extend both along the edge of the side channel and the bank of the Campbell River for approximately 1km. The footprint for this feature would have to be located either: along the riverbank displacing the mature trees in this area (which may not be feasible due to bank erosion – a geomorphic assessment would be required); within property footprints which would be disruptive to residents; or under the road requiring significant re-construction costs. This engineered protection approach may not be feasible, or cost effective in this area, due to the extensive works required to protect the relatively low density development and small area requiring protection.

Similar to option F, an accommodation approach in this area may be appropriate. Due to the mature riverbank trees and extensive vegetation the flow velocities of overbank floodwaters in this area are likely quite reduced. Accommodations to minimize impact of overbank flooding could include changes in basement purpose, elevated flood construction levels, utility relocation, waterproofing of homes, and other similar measures. Accommodation in this area could be legislated as new construction or renovation in the area occurs. As this is a low-density development with the possibility of future infill development, mitigations in this area should be considered with respect to future development plans. Future study of geomorphology, expected flooding frequency, detailed flood construction levels, accommodation feasibility and legislative possibilities is recommended.

I Campbell River north side at Island Highway

On the north side of Campbell River at the North Island Highway bridges, there is potential inundation from the river channel to the residential and commercial areas on the north side of the river. A dike (or raised berm) along the river, especially in the low-lying areas around the bridges would likely reduce inundation in this area. Further study of the extent and elevation of this mitigation is required. A dike in this location, while it could be designed to block flood levels, would likely have a significant impact on channel constriction and flow deflection as well as require tie-in with high ground upstream and downstream. An analysis focused on river and channel morphology changes during flooding may be required to evaluate feasibility and design constraints of mitigations in this area.

5.3 Considerations for Mitigation Options

The mitigation options above should be considered in conjunction with a community planning project which examines future land-use plans. Some of the constructed flood mitigation options considered may be deemed to be infeasible due to cost or required space constraints. In those cases, planning can facilitate accommodation or retreat measures such as SLR zoning which can be implemented effectively over the time horizon that SLR is expected to have significant impact on flood levels.

Choice of mitigation measures should include consideration of the following:

- Future land use and development plans;
- Protection priorities;
- Feasibility of options ;
- Impact of flooding on vulnerable assets; and
- Constraints specific to each mitigation option.

Constraints associated with all engineered protections include: requirement for a significant right of way; impact on fish habitat of associated erosion protection; possible effects on flood levels or erosion due to channel constriction and deflection associated with protection works; internal drainage considerations behind the diked barrier; significant construction costs; and ongoing maintenance costs. To be effective, a dike has to tie into high ground on either end. Some area specific feasibility considerations are outlined in Table 5-1 below.

Given the timescales associated with SLR, it is entirely reasonable to consider a longer time-scale for planning and implementation of mitigation options. Raising land incrementally over time is one approach, and also allows for monitoring of the science of SLR during this period to provide feedback on whether plans should be accelerated or not.

Table 5-1: Feasibility considerations for mitigation options

Mitigation Option	Feasibility Considerations
A	• Potentially large footprint of constructed works and moderately dense development existing in the area • Considerations of existing and future use of land, and needs to residents • Need for continued maintenance
B	• Space appears to be available for infrastructure, possibly under existing trail • Need for continued maintenance
C	• Depending on type of sea dams used, may disrupt connectivity along Nunns Creek (ecological impact) • Need for continued maintenance
D	• Need dependent on expected performance of measures A through C • Potentially restricted available footprint area along creek
E	• Analysis of stormwater capacity and system resilience required • SLR may have significant impact on stormwater system functionality
F	• Operational considerations for seaplane terminals may make accommodation infeasible
G	• Frequency analysis indicating high frequency of expected flooding may make temporary works undesirable • Elevation constraints may make drainage culvert under Spit Road impractical
H	• Protections may be infeasible due to constraints associated with engineering protections • Frequency and flood level analysis is required to establish more detail on accommodation requirements
I	• Potential for large footprint of constructed works • Need for continued maintenance

Within the scope of this assignment we have not examined specific infrastructure vulnerability such as wastewater infrastructure or electrical distribution. This is all critical infrastructure for a community, and should be considered in future work.

6 CONCLUSIONS AND RECOMMENDATIONS

The estuary flood assessment study shows that the flood extents upstream of the Highway 19 Bridge do not vary much amongst the three time horizons (2017, 2050, and 2100) suggesting limited tidal influence upstream of the bridge in these conditions. The flood extents upstream of the Highway 19 Bridge are governed by discharges from John Hart Dam and Quinsam River. Downstream of the Highway 19 Bridge, however, the flood level and extent increase with increases in sea level rise.

Two low areas along the Campbell River were identified as key areas of concern: the shoreline in the area near the Campbell River Lodge on the south bank of the river, and the north bank of the river upstream of the Highway 19 bridge. Both of these locations are key inflow areas for flood waters into residential and commercial neighbourhoods.

The limited vulnerability assessment identified significant impacts associated with the inundation scenarios in terms of zoned areas, infrastructure receptors and vegetation type. Recommended procedure and components for a future vulnerability assessment are provided for an analysis which would provide a more in depth understanding of the impacts of flooding and identify mitigation priorities.

Mitigation measures are identified based on model results and local historical flooding knowledge. While all of these mitigation measures require further study and analysis to move towards design, their identification enables prioritization for further study.

The study shows that:

- Flooding associated with 1 m of SLR puts significant infrastructure and population at risk within the City of Campbell River;
- Mitigation options exist which would protect at risk Campbell River infrastructure and populations; and
- Further study of mitigations coupled with feasibility constraints and protection priorities is required.

As a final comment, this study has examine coastal flood hazard in the Campbell River Estuary for SLR up to 1 m in elevation (year 2100 levels as per BC guidance). Long term planning levels for SLR for are set at 2 m, although there is at present a fairly high uncertainty with respect to timing. It is thus recommended that when considering the findings of this study, planners keep in mind that SLR is not expected to stop at 1 m but to continue to elevations in excess of this level in the long term.

7 REFERENCES

Ages, A. B., and Woollard, A. L. (1991). *Flow Dynamics of the Campbell River Estuary*.

BC Hydro (2012). *Campbell River System Water Use Plan*.

BC Ministry of Environment (2011b). *Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use – Guidelines for Management of Coastal Flood Hazard Land Use*.

BC Ministry of Water, Land, and Air Protection (2004). *Flood Hazard Area Land Use Management Guidelines.* (Amended by BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, January 2018).

Cowichan Valley Regional District (2017). *Cowichan Valley Emergency Preparedness Workbook*. [online] Available from: https://www.cvrd.bc.ca/DocumentCenter/View/84184/MIECM-Emergency-Preparedness-Workbook---2017 (Accessed 23 May 2018).

Han, G., Zhai, B., and Thomson, R. (2016). Twenty-first century mean sea level rise scenarios for Canada. *Canadian technical report of hydrography and ocean sciences*, (313), 1488–5417.

Hervouet, J.-M. (2007). *Hydrodynamics of Free Surface Flows: Modelling with the Finite Element Method*.

Klohn Leonoff Consulting Engineers (1989). *Floodplain Mapping Program. Campbell & Quinsam Rivers*.

McElhanney & Komori Wong Environmental (2004), Nunns Creek Lower Watershed Management Study, Final Report (copy provided by City of Campbell River)

8 CLOSURE

Please do not hesitate to contact Edwin Wang or Grant Lamont (ewang@nhcweb.com | glamont@nhcweb.com) should you wish to discuss this analysis further.