District of Ucluelet Coastal Flood Mapping

Appendix D Coastal Storm Flood Depths and FCL Differences

Table of Contents

1 INTRODUCTION 1

1.1 WHAT IS A FLOOD CONSTRUCTION LEVEL (FCL) AND A SEA LEVEL RISE (SLR) PLANNING AREA? 2

1.2 SUMMARY OF MODEL METHODOLOGY 3

2 FCL METHODOLOGY 4

3 DIFFERENCES BETWEEN PLANNING SUPPORT MAPS AND DEPTH MAPS. 6

4 REFERENCES 9

1 Introduction

A key objective of the District of Ucluelet Coastal Flood Mapping project was to establish flood construction levels (FCLs) for the District of Ucluelet (DOU). These FCLs are based on coastal storm flood hazard and will be used to support planning and policy decisions made in the DOU. The FCLs and FCL maps are designed to balance the application of a conservative approach while avoiding unreasonable land use planning constraints. They were also designed to be easy to read and apply.

The workflow to produce the FCL maps was as follows. The coastal storm flood depth and extent maps were first produced based on output from the hydrodynamic model and interpolation (more details are in Section 5 of the main report). The depth and extent maps were then reviewed and adapted, through simplification and professional judgement. The FCL maps are included in Map Series 2 of the Coastal Flood Hazard Map Atlas (Map Atlas; Appendix C). Map Series 2 also includes the Sea Level Rise (SLR) Planning Area map, which is based on the FCL. Together, the SLR Planning Area and FCL maps are called the planning support maps.

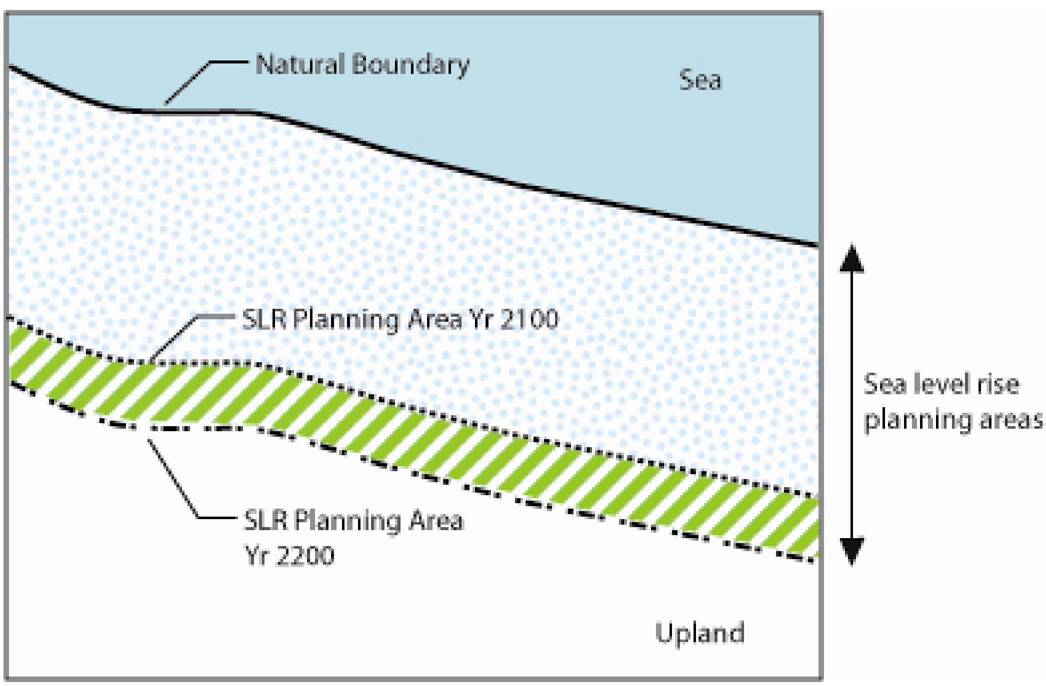
Producing the FCLs resulted in several differences between the model-based depth and extent maps and the planning support maps. This document describes how the FCLs were adapted from the depth and extent maps, the differences between this approach and that used to create the depth and extent maps, and the effect of this difference on the mapped extents.

1.1 What are a Flood Construction Level (FCL) and a Sea Level Rise (SLR) Planning Area?

An FCL is an elevation relative to a datum[1], and it is used in planning to establish the elevation of the underside of a wooden floor system (or top of concrete slab) for habitable buildings. It includes a freeboard (for safety) to account for uncertainties in the analysis.

The *Provincial Guidelines* suggest that the minimum designated storm to be used in the calculation of FCL and SLR Planning Areas is the 0.5% annual exceedance probability (AEP), but that this can be reassessed to 0.2% AEP for heavily populated areas. This project uses the 0.5% AEP storm. In coastal areas, the designated storm consists of several elements including storm surge, wind, and wave effects. The *Provincial Guidelines* also state that a freeboard of 0.6 m should be applied to calculate the FCL for coastal flood mapping.

SLR Planning Areas reach from the natural boundary (defined in the *Provincial Guidelines* as "The visible high watermark") of the sea landward to the contour elevation of the future FCL (Figure 1). The natural boundary of the sea will change over time and move further inland, as sea levels rise. SLR Planning Areas are used to show the change in flood extent over time and may be designated by local governments, by bylaw, as flood hazard areas. SLR Planning Areas show likely future flood extents considering relative sea level rise (RSLR). Due to changes associated with SLR, both the natural boundary and SLR Planning Area are subject to change, and will require revision and updates over time. The latest update to the *Provincial Guidelines* suggests that as a minimum, the FCL for the year 2100 should be established.



[1] For this project the Canadian Geodetic Vertical Datum of 2013 (CGVD2013) is used.

Figure 1: Sea Level Rise Planning Area example (Figure from Ausenco Sandwell 2011a, 2011b, 2011c).

A more detailed discussion on the regulatory context of flood management and land use planning is contained in Section 2.4 of the main report.

1.2 Summary of Model Methodology

This brief description of the hydrodynamic model methodology and the use of transects is included here for context. For a detailed discussion of the flood hazard analysis methodology for coastal storms see Section 4 of the main report.

To calculate total water elevations for the study area the shoreline was split into 48 different sections ("reaches") of approximately 500-m width, with each reach having a similar slope and direction of exposure (Figure 2). For each reach, a transect across the shore from ocean towards inland was constructed that was considered representative of the reach.

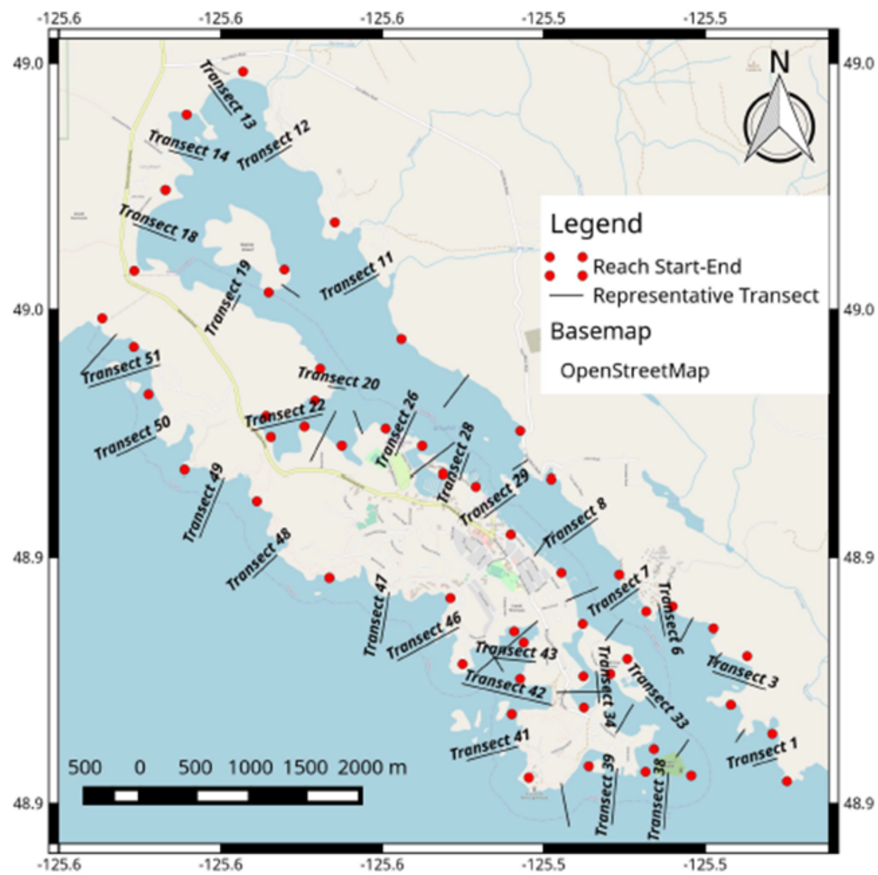


Figure 2: Example of location of shore reaches and representative cross-shore transects. All transects are shown in Appendix A (figure from Cascadia Coast Research Ltd., see also Appendix A).

Wave runup was estimated at each transect. The runup estimated at each transect was considered representative of the runup along the entire reach. It should be noted, however, that variability in shore slope conditions within the reach will result in variability in wave runup that would not be captured. This is particularly true on Ucluelet's exposed western shore, where the rocky shoreline is extremely irregular.

Two approaches were used to calculate wave runup; one for shallower-sloped shores (Northwest Hydraulic Consultants, 2005) and one for steeper slopes (following Van der Meer *et al.* 2016) (see Appendix A for details). The largest wave runup occurred where large waves break on a steep slope; runup alone can exceed 10 m in these areas.

Wave runup was combined with the modelled effects of storm surge, wind set-up and tides at each transect to give a total water elevation which was considered representative of the reach.

2 FCL Methodology

There are many factors that affect the flood levels in a coastal flood event. Hydraulic models analyse the main factors to produce a simulation of a given event, however, they have several limitations in what they can consider and the level of detail they can assess. For example, in this project transects were used to represent reaches approximately 500 m wide. While these reaches were defined based on areas of similar shoreline and transects were considered characteristic of the reach, these do not account for local variation within each reach.

It is possible to address some of this uncertainty through more simulations and more complex modelling methodologies; however, it is not possible to remove all uncertainty. For the planning support maps a balance was essential to provide a conservative, worst-case estimate which addresses this uncertainty while avoiding unreasonable spatial constraints for land use planning. The extreme variability of the western (outer) coastline presented significant difficulties in setting up the hydraulic model and defining FCLs. For this reason, several transects were adjusted from the model results to better allow for local variation. This was done based on a review of the model, the results, and local geography. These changes were as follows:

- Zone 2 – The FCL was increased by 1.5 m for both the 0.5 m and 1.0 m RSLR scenarios. This was based on a review of the modelling and the variations in the local coastline.
- Zone 3 – The zone was divided into 2 sections that are enveloped within the Zone 2 extents. This was done to account for the significant increase in shoreline steepness in Zone 3, when compared to the surrounding coastline.
- Zone 6 – The FCL was increased by approximately 0.3 m to provide an increased factor of safety in this area.
- Zone 7 – An additional non-modelled transect was added in this location. This was based on transect 41, located on the opposite side of the inlet, due to the similarity of the coastline in these two areas.

The changes resulted in 49 transects within the study area. To allow easier integration into flood policy making, we combined transects with similar levels into FCL zones. This resulted in 15 zones defined for the DOU peninsula and a further 3 zones on the eastern side of the inlet. Within each zone, the largest flood level (including freeboard) measured at the transects was used to define the FCL for the whole zone.

The resulting FCLs for each zone were rounded to the nearest 0.1 m. A conservative approach was taken and any level more than 0.03 m above the nearest 0.1 m was rounded up (e.g., 5.14 m became 5.2 m, whereas 4.33 m became 4.3 m).

We clipped the zones using the nearest 0.5 m contour to allow the hazard extent to be mapped. These contours were created from the DEM and are therefore 2 stages removed from the original surface measurement product (the LiDAR). Figure 3 presents a comparison of the 0.5 m contours we created and the equivalent 0.3 m contours provided by the DOU. These are plotted at 1.5 m intervals. Any differences between the two contours are considered minimal. It should be noted that ground levels have not been confirmed through site survey. We recommend that a survey be completed prior to application of the FCLs in any given location to account for any inaccuracies in the LiDAR. For this reason, the minimal differences in contours were not considered critical at this stage.

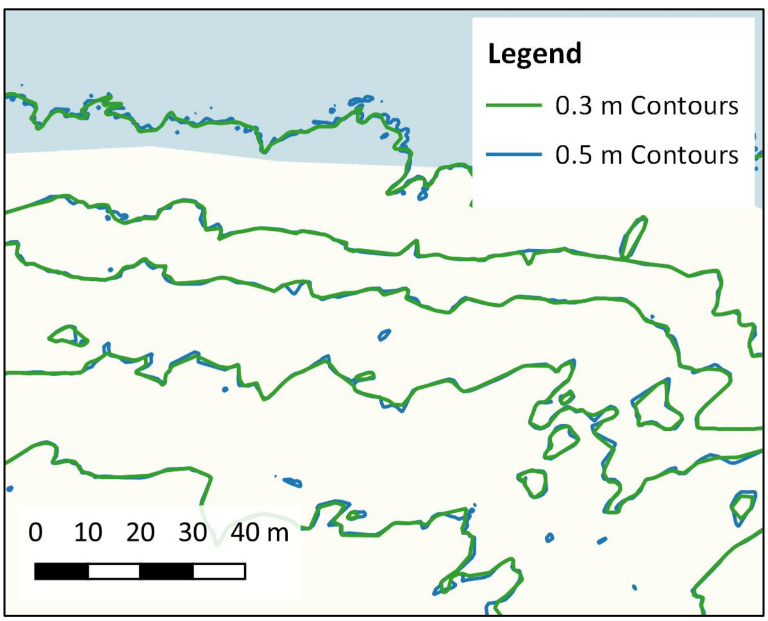


Figure 3: Comparison on 0.3 m contours provided by DOU and 0.5 m contours created from the DEM, plotted at 1.5 m intervals.

Holes in the FCL zone that were less than 1000 m^2 were filled to avoid the false impression of "safe" locations within the zone. These small isolated areas would be surrounded by water in an actual event and would therefore not be considered safe. The FCL identified for the zone would still apply in these areas.

The FCL zones were manually adjusted to ensure that there was only one FCL identified for each land parcel and extents were adjusted in areas where a parcel spanned 2 different FCL zones. This adjustment was done on a conservative basis. Where there was any doubt, a parcel was assigned to the zone with the higher FCL.

3 Differences Between Planning Support Maps and Depth Maps

The depth maps were created to show possible flood depths across the DOU. The flood depth maps are provided for advisory purposes and are not to be used as the basis for policy. They are more scientific in nature and have not been subjected to the same conservative revisions described for the planning support maps. For this reason, there are several notable differences between the planning support maps and the depth and extent maps. These differences are presented in Figure 4.

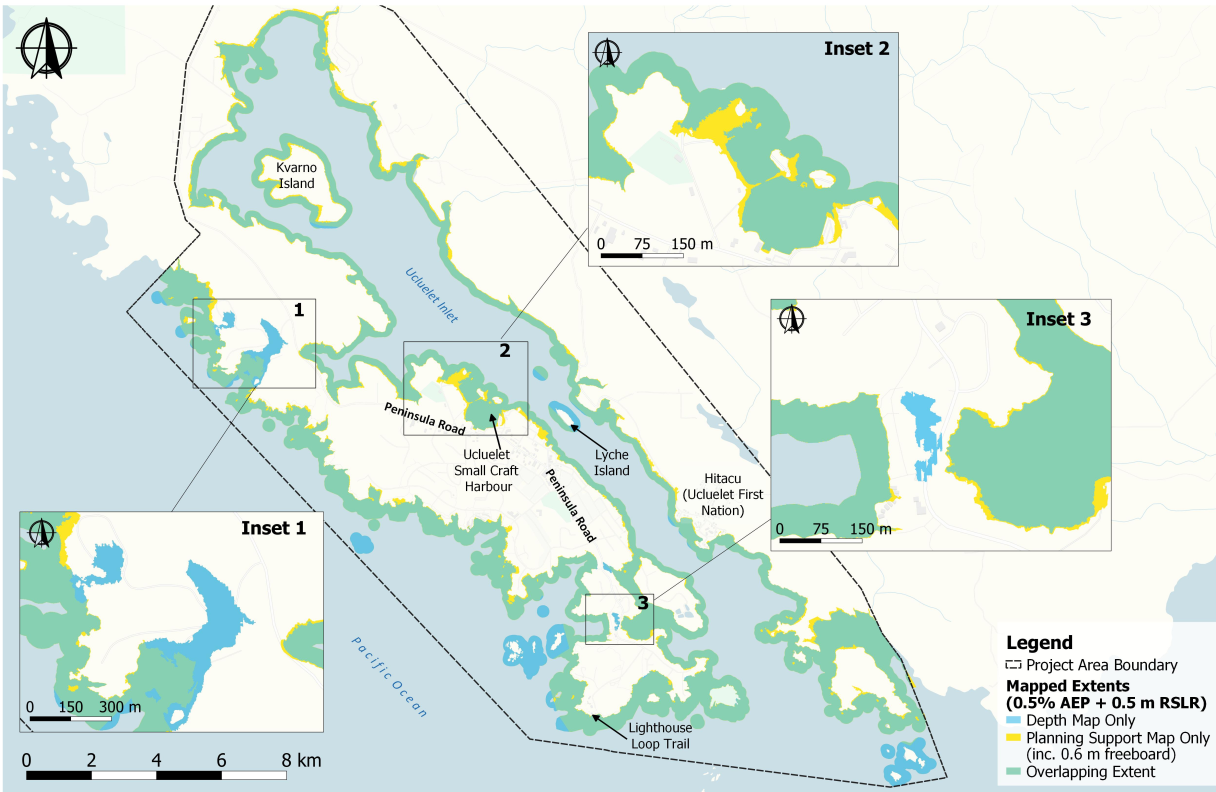


Figure 4: Map showing differences in the planning support and depth map extents for the 0.5% AEP + 0.5 m RSLR scenario.

In most places the differences are relatively minor. The areas of greatest difference and highest uncertainty have been highlighted on the relevant depth maps in Series 2 of the Map Atlas which accompanies the main report (Appendix C). The reasons for the differences are summarized below.

Specific transects were adjusted

The largest differences between the planning support map and depth map extents are the adjustments made to Zones 2, 3, 6, and 7, described at the start of Section 2. These changes were made primarily to account for the extreme variability of the western (outer) coastline of Ucluelet.

The levels of Zone 2 and Zone 6 were increased by 1.5 m and 0.3 m, respectively. This was done based on detailed review of the model to present a worst-case scenario for these areas. This will create an increase in the extents for these zones.

Zone 3 was split due to a shallow-sloped beached area between the two headlands which represented a significant local variation in the coastline. This split has led to a significant decrease in the flood extent in this area when compared to the depth maps, the effect of this is shown in Inset 1 of Figure 4.

An additional non-modelled transect was added for Zone 7, as it was identified that this headland has significantly different geography to the surrounding areas. This has led to an increase in the levels in this area; however, as the slopes are steep in this location the change in horizontal extent is relatively small.

Similar transects were grouped

Transects with similar maximum water levels were grouped to form one FCL zone. The highest water level from all the transects was used to define the zone's FCL. This led to an increase in the water level and therefore extent for the planning support maps. This is the principal reason for the difference shown in Inset 2 of Figure 4.

Freeboard was added

The extents presented in the planning support maps include a freeboard of 0.6 m. This is not included in the depth maps. This increase in levels has led to a small increase in the extents presented. This is visible for the whole study area coastline in Figure 4.

FCL zones were rounded to nearest 0.1 m

FCLs have been rounded to 0.1 m. While this would influence the extents it is considered negligible and would not be noticeable when seen at the scale of the maps presented. This change will also largely be superseded by the effect of clipping to contours, described below.

FCL zones were clipped to contours

To plot a geographical extent to the FCL zone, the extent was clipped to the nearest 0.5 m contour. The impact of this change is relatively small and generally not noticeable, particularly in the steeper frontages where FCLs are highest. The impact is greatest on the eastern (inner) coast and changes the extent presented by approximately 7–8 m in the highest difference locations. The impact of this change only affects the way the zones are presented on the maps (i.e., not the levels themselves). It is therefore considered negligible as it is not noticeable at the scale at which maps are provided. Further, it is recommended that ground levels are confirmed through site survey when using these FCLs for planning purposes. This difference should therefore not impact the application of the FCLs.

Areas between transects were interpolated

The transects are considered characteristic of the reaches they represent and therefore are used to define the water levels for the whole reach. This creates an area of high uncertainty at the boundaries between two different reaches; this often creates a jump in modelled water level. To create the continuous flood depths presented in the coastal storm depth maps a gap was left between the two reaches and the water levels were interpolated across this area. The location of these transition points is critical in defining water levels. The FCL zones are not continuous and therefore do not use interpolation at the reach boundaries. This results in a change in water levels where the FCL zone boundary coincides with the reach boundary. This is the reason for the additional blue area in the top right of Inset 1 in Figure 4.

Flood depths were first estimated in peninsula areas

To create the depth maps, an estimate first had to be made of the potential flood extent before it could be calculated. There are specific challenges in doing this for a peninsula such as the DOU as it has to include an estimate of areas where flood water covers the entire width of the peninsula. These are areas of particularly high uncertainty; a further estimate of the contribution from levels on each side of the peninsula is required. To accomplish this, water levels are interpolated between the 2 sides and the result is compared to the DEM to calculate flood depth. This has resulted in differences between the depth maps and the planning support maps, which do not use this interpolation. An example of this is shown in Inset 3 of Figure 4.

Uncertainty due to overspill

An uncertainty label was added at the end of the peninsula to all depth maps where there was ponding or overspill between the east and west coast. The issue with the differences between FCL extent and depths maps only occurred for the 0.5% AEP for 1 m and 2 m RSLR. However, ponding and overspill also occurred at the peninsula for 6.67% AEP for 1 m and 2 m RSLR. Therefore, uncertainty labels were also added to the 6.67% AEP maps (for consistency in map series, and as uncertainty still persists, even if does not lead to differences between FCL and depth extent).

4 Conclusion

This document has summarized the reasons for the differences between the coastal storm flood depth and extent maps, and the planning support maps (i.e., the SLR Planning Area and FCL maps) resulting from the different methods used to create them. The depth and extent maps were based on the hydrodynamic model outputs. The data were used as the basis for the planning support maps. However, the planning support maps required simplification and professional judgement. Overall, the differences are small. Key areas have been noted on the Series 2 maps of the Map Atlas in Appendix D.

5 References

Ausenco Sandwell (2011a) 'Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use - Draft Policy Discussion Paper'. Prepared for BC Ministry of Environment.

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

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Van der Meer, J. *et al.* (2016) 'EurOtop: Manual on wave overtopping of sea defences and related sturctures - An overtopping manual largely based on European research, but for worlwide application (2nd edition)', pp. 110–111.

Northwest Hydraulic Consultants (2005) *Final Draft Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States*. Prepared for Federal Emergency Management Agency (FEMA).