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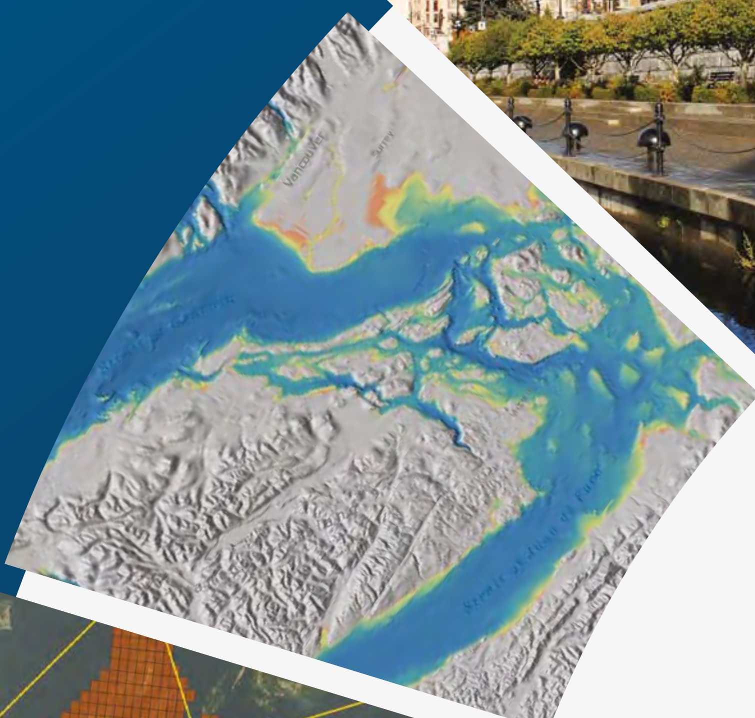
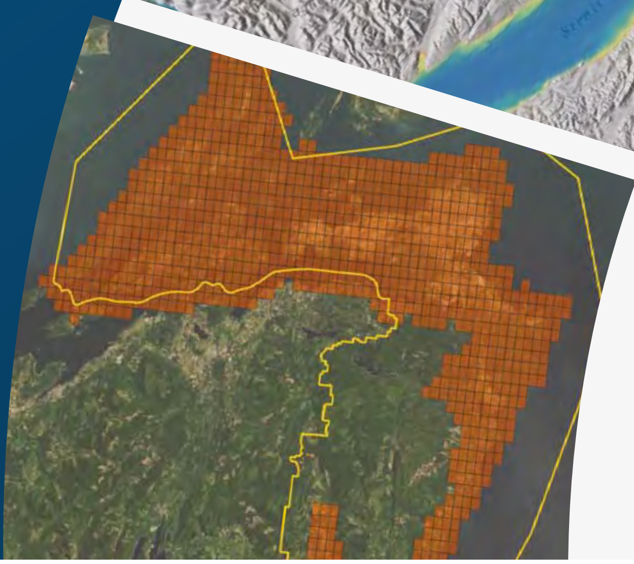
Task 1 – DEM Development Report

Capital Region Coastal Flood Inundation Mapping Project

March 2020 V2.0





Associated Engineering

CANADA BEST MANAGED COMPANIES Platinum member

DHI

WESTMAR ADVISORS

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GLOSSARY

2019 GeoBC raft Li AR		Partially classified 2019 Li AR data (.las files) provided by GeoBC. Used by the project team to create the topographic surface for the Project DEM
2019 GeoBC inal Li AR		ully processed bare earth M using 2019 Li AR provided by GeoBC. Was not available until after the modelling tasks. Used by the project team for a final quality control check of the 2019 GeoBC raft Li AR.
A	Associated Engineering	
AEP	Annual xceedance Probability	The probability of a specific event occurring, or being exceeded, in any given year.
CD	Chart Datum	The local datum for oceanographic measurements (e.g. tides) at a specific port or harbour.
CGVD1928	Canadian Geodetic Vertical atum 1928	Vertical elevation reference system, which is to be superseded by CGVD2013.
CGVD2013	Canadian Geodetic Vertical atum 2013	Vertical elevation reference system, which supersedes CGVD1928.
CHS	Canadian Hydrographic Service	
CRD	Capital Regional District	Regional government for 13 municipalities and three electoral areas on southern Vancouver Island and the Gulf Islands. 'Capital Region' refers to the specific geographic area within the CRD's jurisdictional boundaries.
CSRS	Canadian Spatial Reference System	
CSZ	Cascadia Subduction Zone	
M	Digital Elevation Model	
L	Designated Flood Level	
DHI	Danish Hydraulic Institute	
DS	Designated Storm	
M	Digital Elevation Model	Generic term for elevation model
DTM	Digital Terrain Model	A form of DEM which generally excludes vegetation and built features.
DSM	Digital Surface Model	A form of DEM which includes vegetation and built features.
F	etch	
FCL	Flood Construction Level	As per Provincial Guidelines, defined as the underside elevation of a wooden floor system, or the top elevation of a concrete slab, for habitable buildings.
CRP	lood Construction Reference Plane	

MA	ederal mergency Management Agency	
B	reeboard	
GIS	Geographic Information Systems	
GNSS	Global Navigation Satellite Systems	
HHWLT	Higher-High Water Large Tide	The average of the annual highest tides over the 18.6 year tide cycle.
IPCC	Intergovernmental Panel on Climate Change	
.las		Industry file format for the interchange of Li AR data.
.laz		Compressed version of a .las file.
LiDAR	Light Detection and Ranging	
MFLNROR	BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development	
MSL	Mean Sea Level	
MWL	Mean Water Level	
NA 83	North American atum of 1983	
NAVD88	North American Vertical Datum of 1988	
NOAA	National Oceanic and Atmospheric Administration	
NRCan	Natural Resources Canada	
NTHMP	National Tsunami Hazard Mitigation Program	
Project DEM		Topographic and bathymetric elevation data files prepared for use in the Task 2 and Task 3 modelling and mapping.
SLR	Sea Level Rise	
SWL	Still Water Level	
TIN	Triangular Irregular Network	
TWL	Total Water Level	Total water level at a shoreline, as a combination of tides, storm surge and wave runup.
UTM	Universal Transverse Mercator	

1 INTRO UCTION

1.1 Project Overview

Associated Engineering (A), DHI Water & Environment Inc. (DHI) and Westmar Advisors (Westmar) were appointed by the Capital Regional istrict (CR), as per an agreement executed on August 8, 2019, to undertake the “Capital Region Coastal lood Inundation Mapping Project”; hereafter referred to as the “project” or the “study”. It is important to define that the CR refers to the regional government for 13 municipalities and three electoral areas on southern Vancouver Island and the Gulf Islands. The term ‘capital region’ refers to the specific geographic area within the CRD’s jurisdictional boundaries. These definitions are used throughout this report.

The project has been based on the overarching tasks summarised below:

- **Background Data Collection**: Gathering the available historic reports, analyses and geospatial data.
- **DEM Development**: Creation of a digital elevation model that can be used in hydraulic models to simulate coastal flooding.
- **Sea Level Rise (SLR) Flooding Analysis**: Development of coastal flood construction levels (FCLs) for the capital region using transect analyses; as well as detailed inundation modelling in select locations.
- **Tsunami Source Identification**: Review of available scientific literature and analyses to select appropriate tsunami-generating sources for modelling.
- **Tsunami Modelling**: Development of hydraulic models that can simulate tsunami wave propagation from source to inundation of the coast.
- **Mapping & Reporting**: Summarising the significant volume of technical work completed in concise reporting, accompanied by inundation and transect mapping.

The purpose of this report is to describe the methodology and data sources used to derive the project’s Digital Elevation Model (Project DEM), comprised of topographic (land surface) and bathymetric (sea floor surface) files covering the project domain. The Project DEM was used as a base input to run hindcast spectral wave models, transect analyses, as well as overland inundation models. For further information on these technical analyses, please refer to Task 2 (Sea Level Rise Modelling & Mapping) and Task 3 (Tsunami Modelling & Mapping) reporting.

This report and the information contained herein supersedes the finalised report (v1.0), previously issued in March 2020.

1.2 Study Area

The capital region is located on southern Vancouver Island, with an area of approximately 4900 km^2. The study’s approximately 1300 km long coastline is bounded by Juan de uca Strait to the south-west, Haro Strait to the east and the Strait of Georgia to the north-east. The capital region also shares an international boundary with the US State of Washington. The study area is shown in igure 1-1. There are many irst Nations communities and lands within the capital region bounds, as shown in Figure 1-2.

The study coastline is extremely complex, varying between steep rocky bluffs, gently-sloping beaches and urban marinas/waterfronts. The coastline is well developed, particularly in its eastern extents, with numerous private residences, tourist amenities, commercial industries, transportation facilities and military installations.

The study area includes the Southern Gulf Islands, of which, Salt Spring Island, Galiano Island, Saturna Island, Mayne Island, North Pender Island and South Pender Island are the most notable. The CRD is the regional government for the capital region, being comprised of 13 municipalities and 3 electoral areas. The region hosts a number of significant population centres, with greatest density being concentrated around Victoria and the Saanich Peninsula.

The study area is affected by coastal processes in the Strait of Georgia and Juan de uca Strait. These processes include large tidal variations, and moderate local waves and storm surge generated by strong local winds within both straits. The study area is also affected by potential tsunami hazards, including those generated:

- Locally within the Strait of Georgia, Juan de Fuca Strait and the Puget Sound,
- By a major earthquake within the Cascadia Subduction Zone, and
- Other tsunamis generated from other parts of the Pacific Ocean e.g. Alaska.

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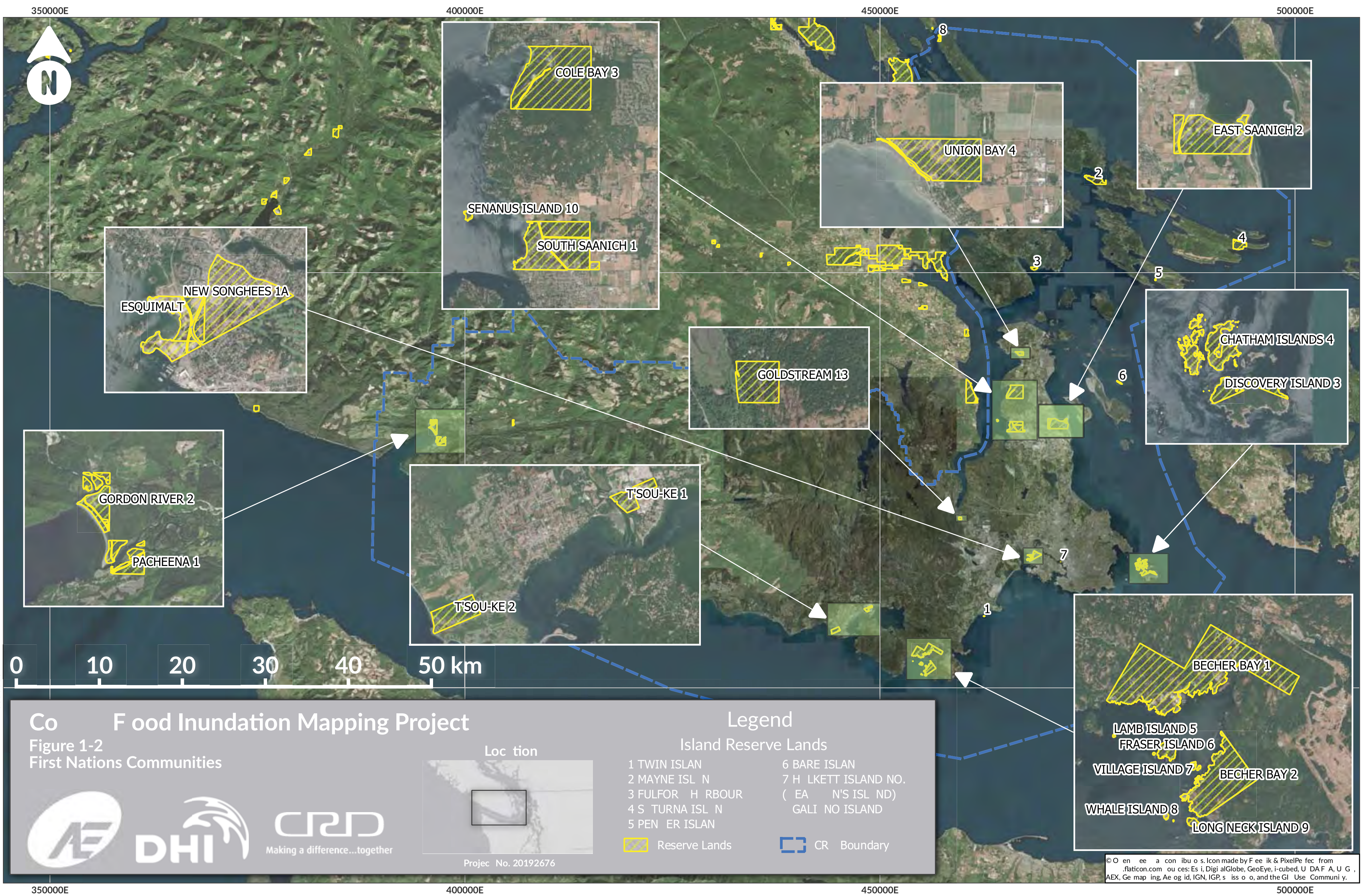
350000E
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COLE BAY 3
SENANUS ISLAND 10
SOUTH SAANICH 1
UNION BAY 4
EAST SAANICH 2
NEW SONGHEES 1A
ESQUIMALT
GOLDSTREAM 13
CHATHAM ISLANDS 4
DISCOVERY ISLAND 3
GORDON RIVER 2
PACHEENA 1
T'SOU-KE 1
T'SOU-KE 2
BECHER BAY 1
LAMB ISLAND 5
FRASER ISLAND 6
VILLAGE ISLAND 7
BECHER BAY 2
WHALE ISLAND 8
LONG NECK ISLAND 9
0 10 20 30 40 50 km
Co F ood Inundation Mapping Project
Figure 1-2
First Nations Communities
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Loc tion
Projec No. 20192676
Legend
Island Reserve Lands
1 TWIN ISLAN
2 MAYNE ISL N
3 FULFOR H RBOUR
4 S TURNA ISL N
5 PEN ER ISLAN
6 BARE ISLAN
7 H LKETT ISLAND NO.
(EA N'S ISL ND)
GALI NO ISLAND
Reserve Lands
CR Boundary

2 XISTING TOPOGRAPHIC & BATHYMETRIC INFORMATION

2.1 Important GIS Descriptions

The production of the Project M involved an understanding of many different types of GIS file formats and processing routines. This was particularly important due to the diverse origins of each input dataset considered in the Data Collection and Review phase of this project. The following sub-sections describe some important GIS concepts that were critical to the completion of Task 1.

2.1.1 Li AR/Point Cloud

LiDAR (Light Detection and Ranging) is a remote-sensing technique that uses laser light to densely sample the surface with x,y,z measurements[1]. Point cloud data can be another term for LiDAR data. The point clouds consist of 3D elevation points, each containing x-, y- and z-values, as well as other metadata. Figure 2-1 shows an example point cloud, the different colours denoting differences in elevation.

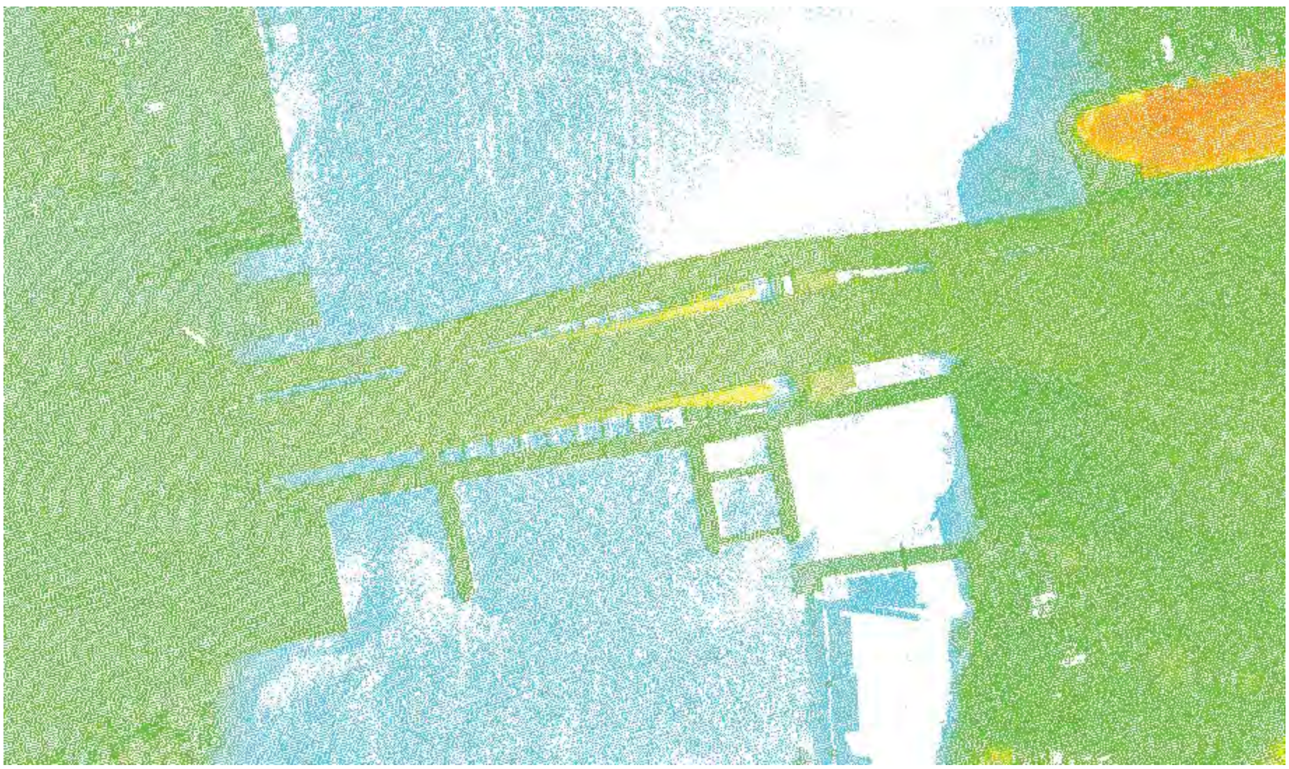

Figure 2-1
xample of Supplied Point Cloud Data

After initial collection of the LiDAR, the dataset is then calibrated and classified. Classification involves defining the type of object that has reflected the laser pulse. Typical classification categories include undefined, bare-earth, vegetation, water, buildings, etc. The different classes are defined using numeric integer codes in the .las files. These

[1] https://desktop.arcgis.com/en/arcmap/latest/manage-data/las-dataset/essential-las-dataset-vocabulary.htm

codes can be used to filter different types of LiDAR points, giving different types of datasets, depending on the user's preference.

A .laz file is simply the zipped/compressed version of a .las point cloud[2]. LAS is an open standard file format that allows for easy exchange of LiDAR data between vendor and client. Point clouds (.las format) are typically classified prior to delivery to the client. The end-user then typically generates Digital levation Models (Ms) which take the form of Digital Terrain Models (TMs) or Digital Surface Models (SMs), both of which are types of rasters. Typically, a DTM will include only bare-earth data and excludes any built features (such as buildings and bridges) and vegetation. A DSM generally includes built features and vegetation. However, for this project, only a DTM was produced (DSMs are typically not used for hydraulic modelling projects; water flows along the ground rather than across building roofs). The influence of buildings on overland flows is typically dealt with in hydraulic models by increasing the floodplain roughness under their footprint[3].

2.1.2 Raster

A raster is a matrix of cells (or pixels) organised into a grid where each cell contains a value representing information, such as elevation, bathymetry, etc.[4] Rasters can also be digital aerial photographs, satellite imagery and scanned images. An example of a raster dataset, in the form of a digital elevation model, is shown in Figure 2-2.

[2] https://desktop.arcgis.com/en/arcmap/latest/manage-data/las-dataset/what-is-a-las-dataset-.htm
[3] Please refer to Task 2 Sea Level Rise Modelling & Mapping Report for further details.
[4] https://desktop.arcgis.com/en/arcmap/10.3/manage-data/raster-and-images/what-is-raster-data.htm

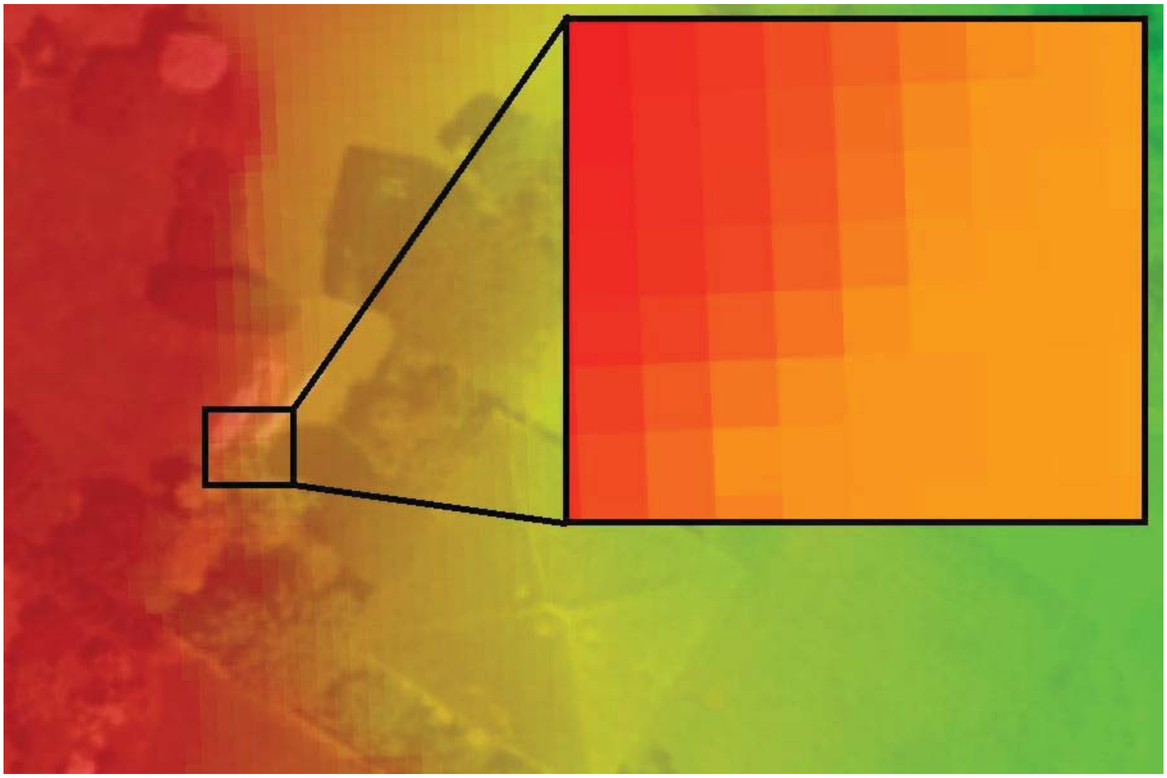

Figure 2-2
xample of a Raster   ataset (Digital   levation Model)

The level of detail represented by a raster is primarily dependent on its resolution (i.e. the size of its cells). A 1 m DTM will be topographically more accurate than a 20 m DTM, for example, even if derived from exactly the same input point cloud. Rasters (more specifically, their pixels or cells) can be stored in a number of different ways, which is why there are a number of different file extensions/names associated with elevation datasets (e.g. ASCII Grid,   SRI Grid, Floating Point   ile, G   AL Virtual Format, Tagged Image File   ormat (TIFF), etc.).   or this particular project, the files were primarily in ASCII and TIFF formats.

2.1.3 TIN Surface

Triangular irregular networks (TINs) are a method of representing surface morphology (elevation datasets) by converting vector-based geographic data into a triangulated set of vertices[5]. In this project, the points are used and connected by a series of lines/edges to form the completed network of triangles.

The triangles' nodes can be placed irregularly over a surface; as such, TINs can have a higher fidelity (relative to rasters) in areas where surfaces are highly variable or where enhanced detail is required. Raster datasets, however, may actually omit critical detail, depending on the cell resolution chosen. The accuracy/level of detail contained within

[5] https://desktop.arcgis.com/en/arcmap/latest/manage-data/tin/fundamentals-of-tin-surfaces.htm

a TIN depends on the method of interpolation for generating the triangles; as well as the means stipulated by which no/null data is processed[6]. An example TIN surface, using point data, for the centre of Victoria is given in Figure 2-3.

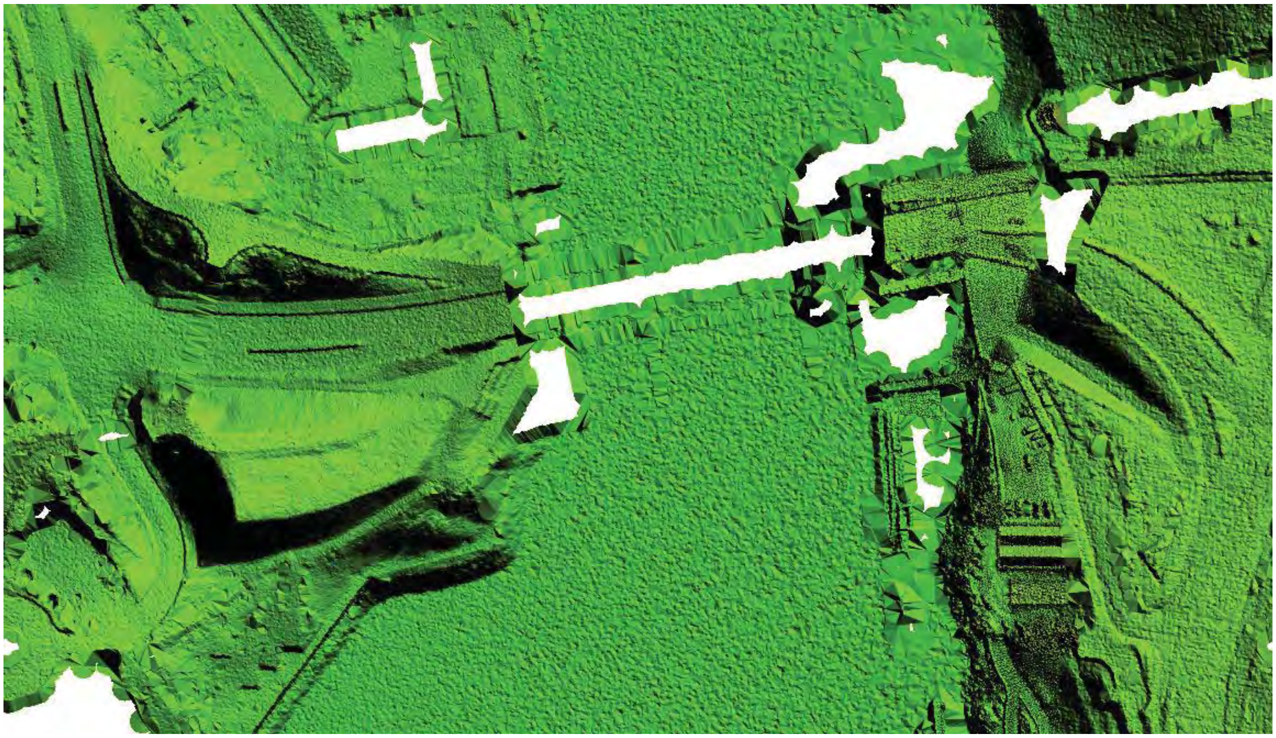

Figure 2-3
Example of a Triangular Irregular Network

2.1.4 Datums

An important facet of interpreting height information in coastal analysis is the vertical datum one uses for reference. A datum is simply any permanent line, plane or surface from which heights or elevations are referenced. When on land, elevations are typically reported to Canadian Geodetic Vertical atum 1928 or 2013, both of which are explained in greater detail in Section 2.2. However, when reporting important water level information in coastal environments, elevations are usually referenced to **chart datum**. Chart datum is the plane or level to which elevations or tide heights are referenced to (igure 2-4). In a North American setting, this datum is usually **Low Water atum**. very major port or harbour has their own chart datum against which tide heights etc. are referenced. Chart datums for each location can be reviewed in greater detail in Canadian Tide and Current Tables or Nautical Charts, produced by the Canadian Hydrographic Service. Many of the elevation datasets reviewed for this project are referenced to different datums (please see Table 2-1) thereby requiring an understanding of the difference between each.

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[6] For further information on the TIN creation process, please see: https://www.bluemarblegeo.com/knowledgebase/global-mapper-20/Create_ levation_Grid_from_3D_Vector_Data.htm

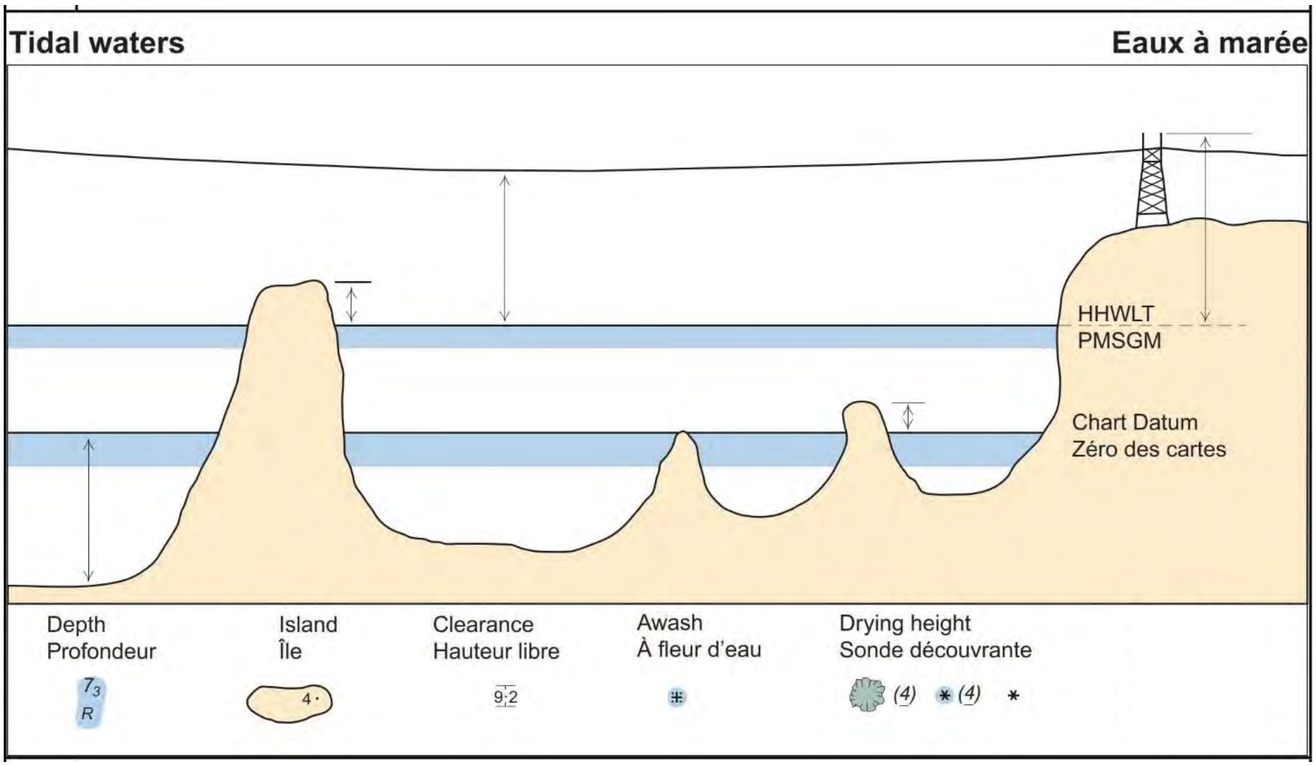

Figure 2-4
Coastal Plane of Reference (Canadian Hydrographic Service, 2016)[7]

2.1.5 Projections/Coordinate Systems

For any project of this scale, that requires manipulation of data over spatial extents, the understanding of map projections/coordinate systems becomes extremely important. Coordinate systems provide a common reference for various sources of geographic information, allowing it to integrate relatively seamlessly. Typically, for engineering studies like this one, a projected coordinate system is used. A projected system (such as Universal Transverse Mercator (UTM), BC Albers etc.) takes the earth's spherical surface and approximates it on a 2-D plane. This allows for consistent distance measurement, in metres, on GIS software, maps etc.[8]. For this study, all project outputs are referenced using UTM Zone 10 North.

Some of the larger project inputs, such as tsunami modelling boundary conditions, are referenced to a 'global coordinate system' i.e. Latitude-Longitude. However, such a system would not provide a consistent distance measurement in outputted mapping. A comparison between global and projected coordinate systems is shown in Figure 2-5[9]:

[7] http://charts.gc.ca/documents/publications/Chart1-Carte1.pdf
[8] https://desktop.arcgis.com/en/arcmap/10.3/GUI -BOOKS/MAP-PROJ CTIONS/WHAT-ARE-MAP-PROJECTIONS.HTM
[9] https://www.earthdatascience.org/courses/earth-analytics/spatial-data-r/intro-to-coordinate-reference-systems/

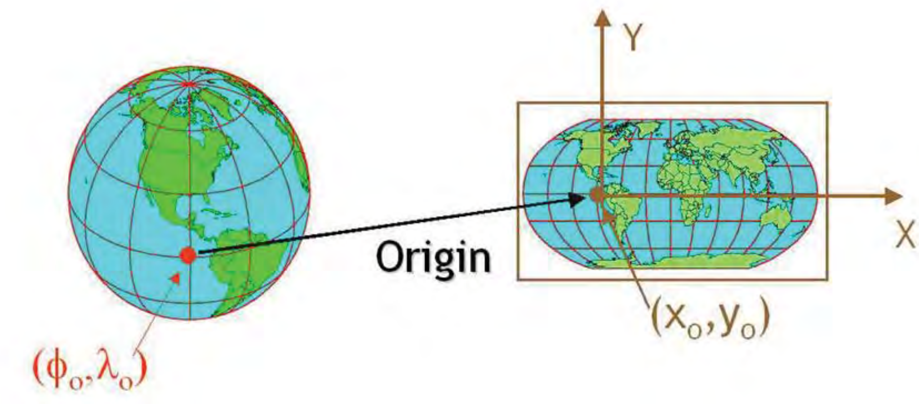

Figure 2-5
Global vs. Projected Coordinate Systems

2.2 Project Elevation Datums

A complicating factor of this project is the necessity of handling topographic data with two different vertical datums: Canadian Geodetic Vertical atum 1928 (**CGV 28**) and Canadian Geodetic Vertical atum 2013 (**CGVD2013**). A vertical datum is the benchmark against which elevations are reported. Historically, elevations were reported using the CGVD28 vertical datum. It is a tidal datum defined by the mean water level at five different tide gauges: Yarmouth and Halifax on the Atlantic Ocean, Pointe-au-Père on the St. Lawrence River, and Vancouver and Prince Rupert on the Pacific Ocean. The datum was propagated throughout the country using geodetic levelling measurements, which yielded 94,000 benchmarks for surveyors to tie into. Typically, when someone states that an elevation is at 'X' m geodetic, they are most likely referring to an elevation using the older CGVD28 datum.

However, with the advent of contemporary Global Navigation Satellite Systems (GNSS) such as GPS, a more precise system was achievable. Thus, Natural Resources Canada (NRCan) released CGVD2013 to modernize Canada's vertical reference system. CGV 2013 is defined by the equipotential surface W_0=62,636,856.0 m^{2}s^{-2}; the coastal mean sea level for North America. It enables measurements of elevations with respect to a consistent vertical datum everywhere across Canada using GNSS and emerging technologies.

However, problems occur when applying the change in vertical datum to existing and future datasets. The difference between CGV 2013 and CGV 28 is not a constant; it varies spatially, depending on where you are in Canada, as shown in igure 2-6. Locally, for most places in BC, CGVD2013 datum is below CGVD28 datum. For example, reporting CGVD28 elevations in CGV 2013, requires a shift of +0.40 m in Revelstoke, whereas South Vancouver Island requires a +0.13 m shift. Even at a regional scale, the difference between datums is not a constant, as evident in Figure 2-7 which shows the relative change between CGVD2013 and CGVD28 across the capital region. Therefore, it will be difficult for municipalities to convert their existing reports, record drawings, and datasets to the new datum.

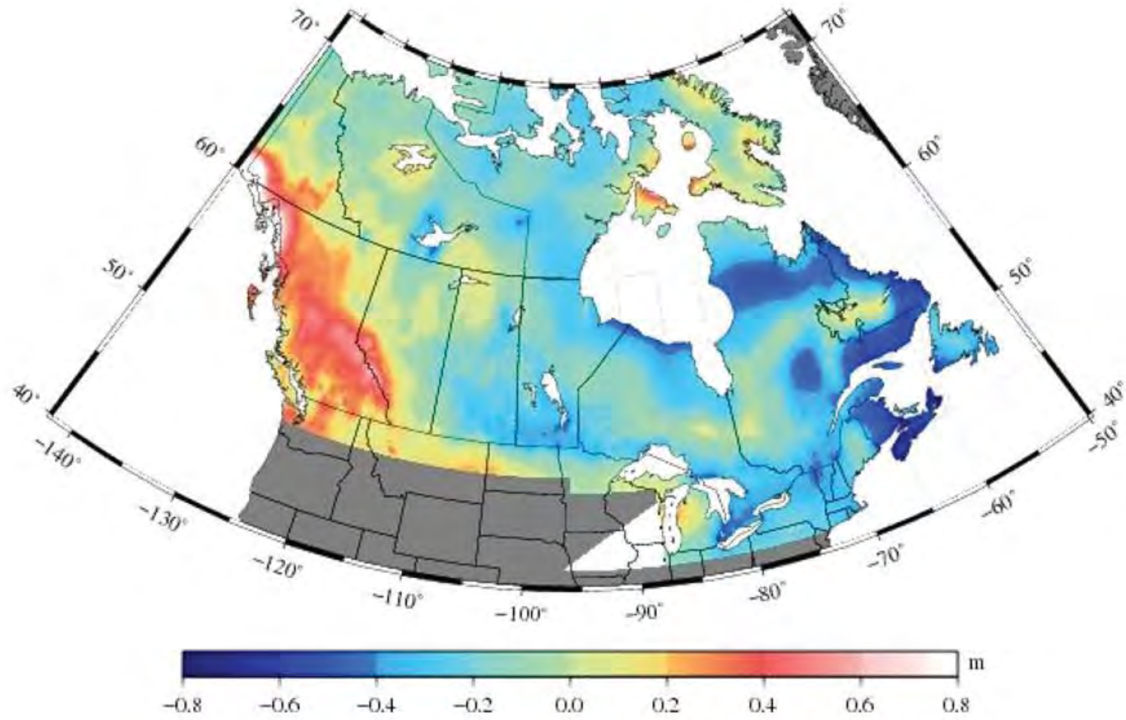

Figure 2-6
Conversion between CGV 28 and CGV 2013 across Canada

The new GeoBC Li AR was flown to CGV 2013, however all of the existing capital region elevation datasets are to CGVD28. or the purposes of this project, CGV 2013 was adopted as the reporting datum. Therefore, all deliverables for this project will be referenced to CGVD2013:

$$Elevation\ reported\ to\ CGVD2013 = Elevation\ reported\ to\ CGVD28\ + Site\ Specific\ Conversion$$

As demonstrated in igure 2-7, there is not a consistent conversion across the capital region between the datums. NRCan's conversion grid[10], which can be downloaded from their website, was used to convert elevations reported in CGVD28 to CGVD2013.

[10] https://webapp.geod.nrcan.gc.ca/geod/data-donnees/geoid.php

or the time being, NRCan intends for both vertical reference systems to exist side-by-side in the short-medium term, to allow users to smoothly transition to the new geoid model. or site-specific work, like subdivision development or municipal structure replacement/construction, the disruption due to the new datum should be minimal, as it will only require one site-specific conversion. However, the greatest impact will be felt on projects like this one, which encompass large areas. In these cases, conversions between CGV 28 and CGVD2013 could be significantly different, depending on location. This will continue to be a problem that public bodies and private businesses must resolve in the years to come. As previously stated, this has manifested itself on this project as some background GIS information is referenced to CGVD28 (i.e. the old datum), thereby necessitating a conversion. **It is also important to note that all deliverables produced as part of this project are to be referenced to CGVD2013**. **Any users/readers of this report, as well as Task 2 and 3 deliverables, must ensure that they understand the difference between the old and new datum for their particular interest area.**

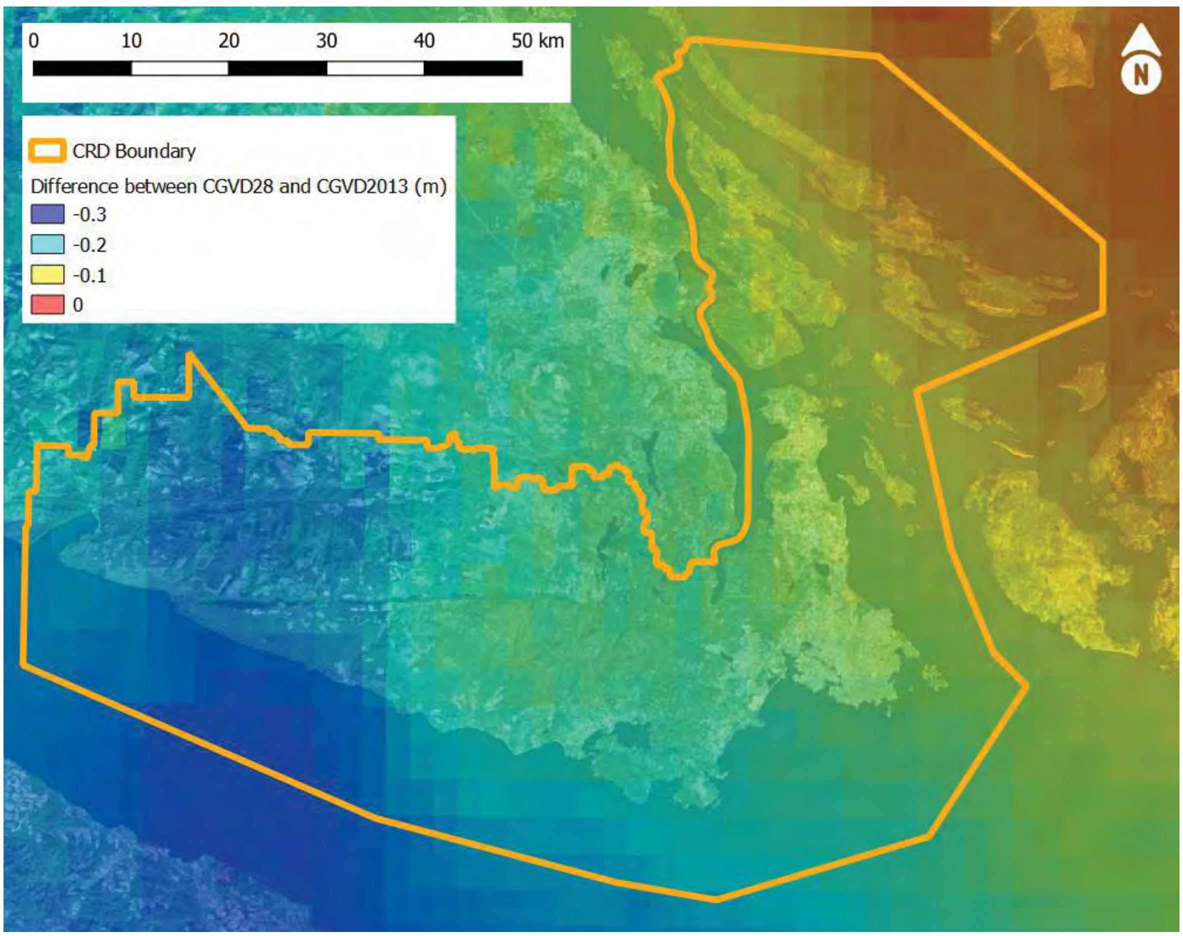

Figure 2-7
Conversion between Elevations Reported in CGVD2013 to CGVD28 within the capital region

2.3 xisting Information Sources

The available elevation data sets within the study area come from a variety of sources, have varying coverage areas, and different levels of details. The complete project DEM, as described in the introduction, is a collation of the most recent and highest resolution data available. Additional considerations in preparing the data for use include the vertical and horizontal datums used, the projection, and the file format. Table 2-1 summarizes the elevation data used for the project.

Table 2-1
Topographic and Bathymetric Information used for the Project

ataset Name	Date	Source	Coverage Area	Vertical Datum	Horizontal Datum	File Format	Purpose
2019 GeoBC raft Li AR	2019	GeoBC	Project Area	CGV 2013	NA 83	.laz	Primary Project M Definition
2019 GeoBC inal Li AR	2019	GeoBC	Project Area	CGVD2013	NAD83	.asc	uality Control of 2019 GeoBC raft Li AR[11]
5m Bathymetry	Varies	CHS	Salish Sea	Chart Datum	WGS84	.txt	Primary Project M Definition
1/3 Arc Second Bathymetry	Varies	NOAA	Salish Sea	MSL	WGS84	.asc	Secondary (in-fill) Project EM Definition
1m Contour	Varies	CRD	Project Area	CGVD28	NAD83	.gdb	Screening for Detailed Model Areas
2013 Li AR	2013	CRD	Victoria – Swartz Bay Corridor	CGVD28	NAD83	.tif	uality Control of 2019 GeoBC raft Li AR
Gulf Island Li AR	Unknown	Island Trust	Gulf Islands	Unknown	NA 83	.adf	uality Control of 2019 GeoBC raft Li AR

[11] The 2019 GeoBC inal Li AR data was not available at the onset of the project, and therefore was not able to be used in the Project EM. However, receipt of the final data allowed for a final quality control check to confirm the accuracy of the 2019 GeoBC raft Li AR surface.

2.3.1 2019 GeoBC Draft LiDAR

The 2019 GeoBC raft Li AR data is a key part of the Project M as it was used to create all of the topographic (land) elevation rasters within the study area. The data was collected in 2019 and provided in a draft form to the project team by GeoBC. At the outset of this study, the finalized data set was not ready for release; only partially processed data in the form of .laz files was available. Complete classification had not been done, and points were only classified as "ground" or "unclassified". Bare-earth points (those which represent the ground surface rather than buildings or vegetation) have been classified as such[12]. Water points, however, had not yet been classified as such, and were included in the ground classification.

The .laz data set consists of multiple files, each of which includes the data for an individual "tile" (Figure 2-8) which collectively cover the study domain. ach of the 1096 tiles is approximately 1840 m wide by 1390 m high, covering an area of 2.5 km^2.

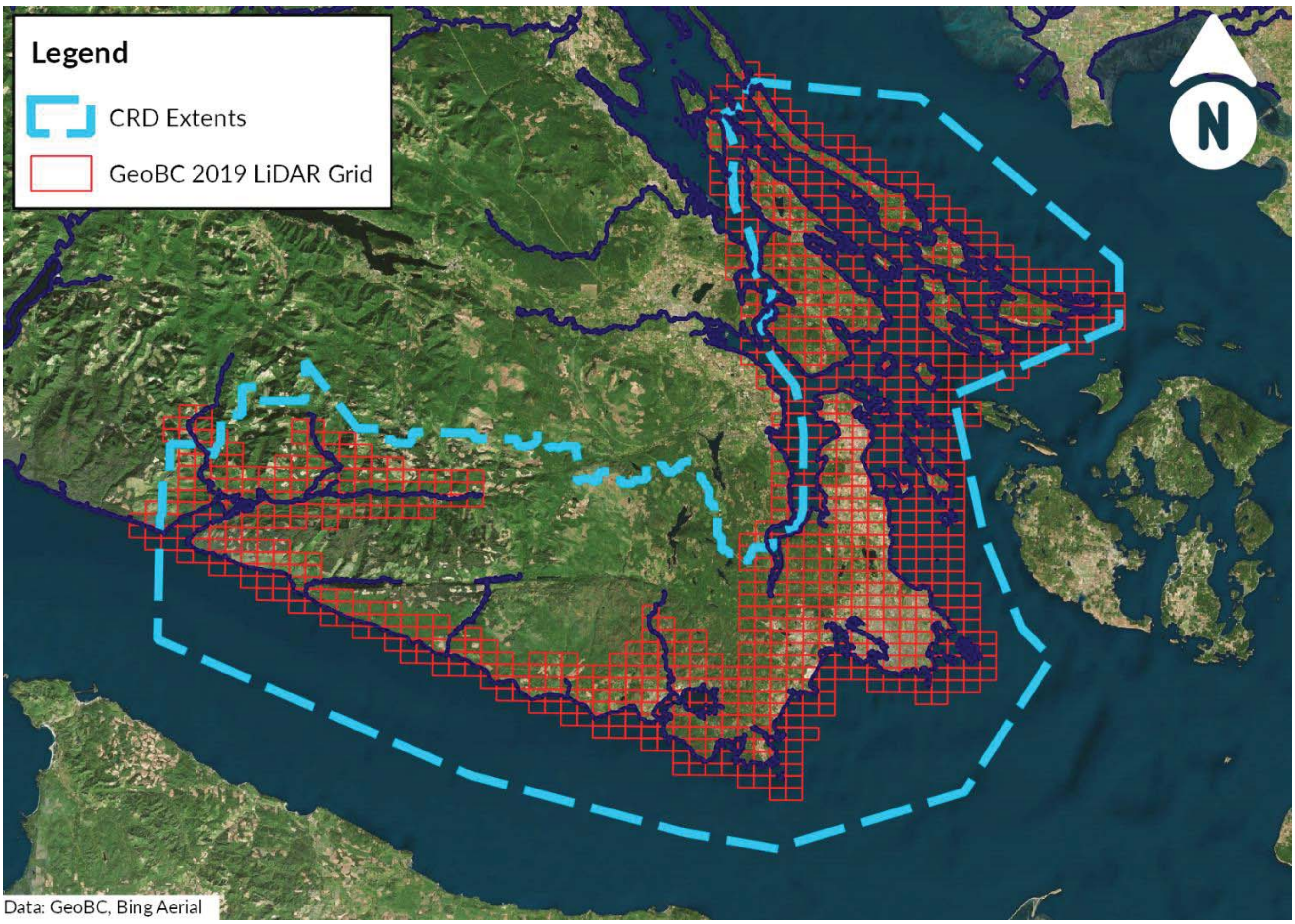

Figure 2-8
GeoBC 2019 Li AR ata Coverage

[12] To reiterate, this Task's primary output is a Digital Terrain Model (DTM), i.e. a 'bare-earth model', coupled with processed bathymetry data. A Digital Surface Model (SM), i.e. including buildings and tree canopy, has not been produced or used.

Figure 2-9 shows an example of the point clouds contained in two tiles in the vicinity of Victoria. The point density on land is approximately 17 pt/m² based on the average density of three selected 10 m x 10 m areas.

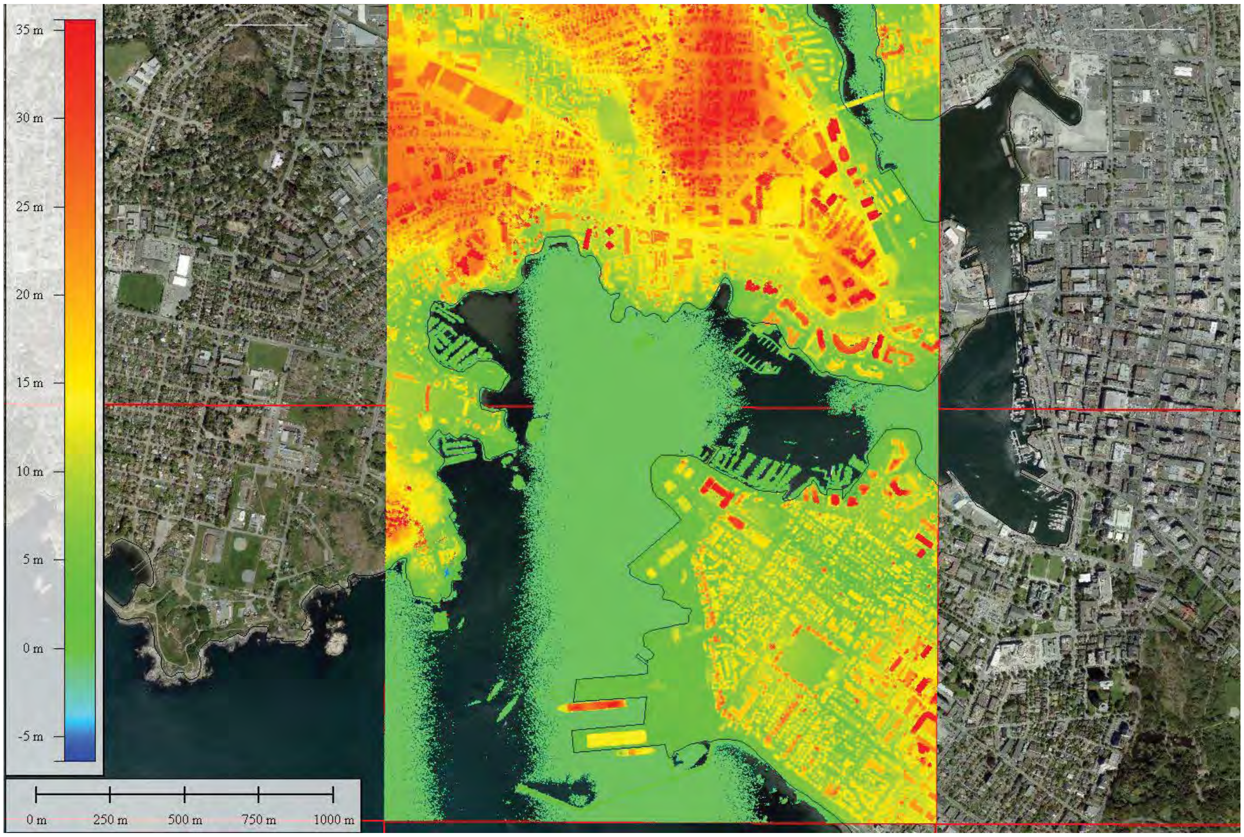

Figure 2-9
GeoBC 2019 Li AR Point Cloud Example

Near the end of the project (May 2020; during the final reporting stages), the 2019 GeoBC inal LiDAR data became available. This was used for a final quality control check to confirm that the 2019 GeoBC raft Li AR surfaces were processed correctly (Section 3.2.6).

2.3.2 CHS 5m Salish Sea Bathymetry

The Canadian Hydrographic Service[13] (CHS) provided, under agreement, 5 m bathymetry data which encompasses the project study area. This data comprises the majority of the bathymetric component of the Project DEM. igure 2-10 below outlines the coverage of the CHS dataset. The data includes a single text file for each area shown in the figure, with data in the format of latitude/longitude/elevation. The project study area falls within the boundaries of four of these datasets: MetroVan, SouthVI_1, SouthVI_2, and MidVI. As seen in igure 2-10, there are some gaps in the data coverage (e.g. in the Juan de uca Strait). To fill these gaps in the project DEM, additional bathymetric data from the US National Oceanic and Atmospheric Administration (NOAA) was obtained.

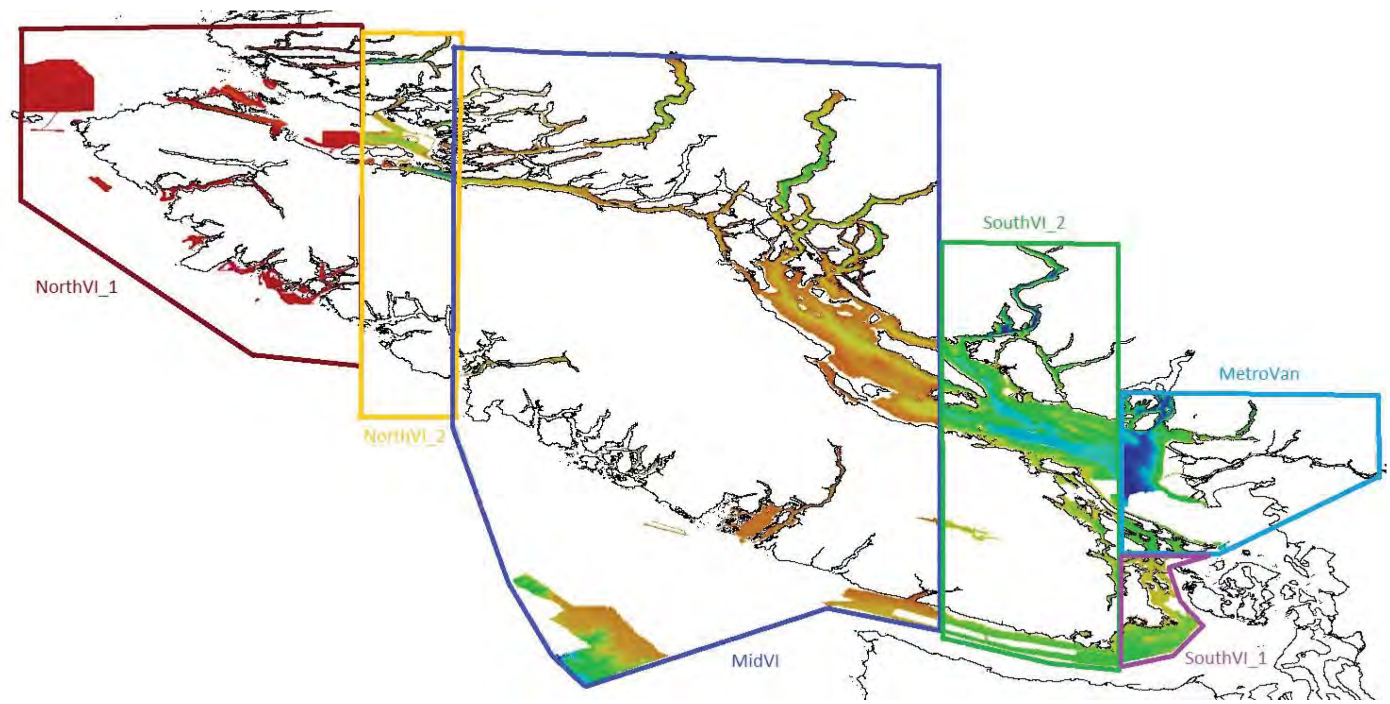

Figure 2-10
CHS 5m Bathymetry Coverage

[13] https://inter-j01.dfo-mpo.gc.ca/registry-registre/orderMap-commanderCarte?lang=eng

2.3.3 NOAA 1/3 Arc Second Bathymetry

The US National Oceanic and Atmospheric Administration (NOAA) has made bathymetric data publicly available[14]. In the vicinity of southern Vancouver Island, the data resolution is 1/3 arc-second, or roughly 10 m. Figure 2-11 shows the data extents covering the project study area. Other areas of the Salish Sea and Canadian Coastal waters are resolved at 3 arc-second, or roughly 90 m. The NOAA data files are in the .asc ASCII grid format. This data was used in the Project DEM to fill any data gaps in the CHS bathymetry.

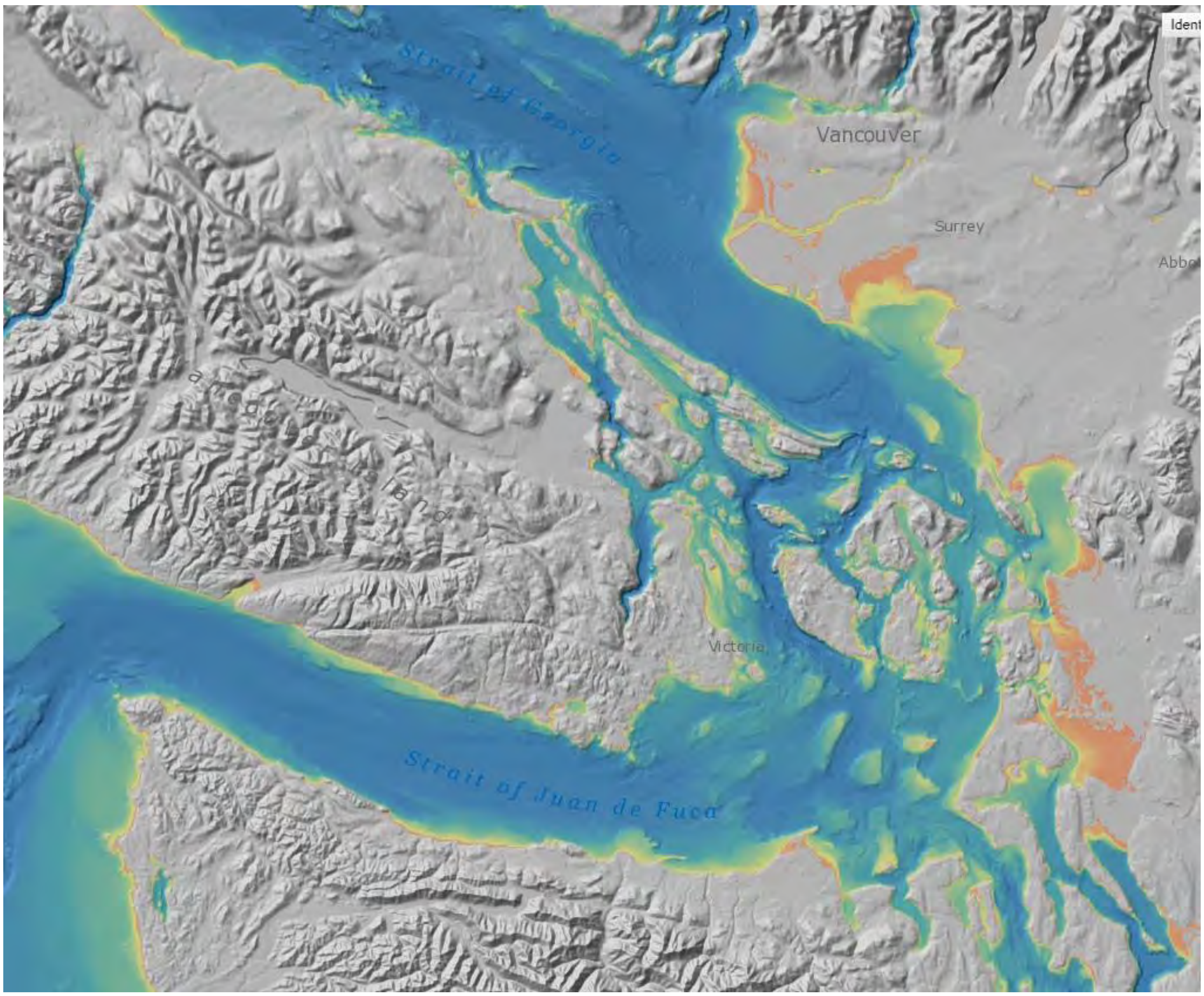

Figure 2-11
NOAA 1/3 Arc-Second Bathymetry Data Coverage

[14] https://maps.ngdc.noaa.gov/viewers/bathymetry/

2.3.4 CRD 1 m Contours

Contour data for the study area was provided by the CR [15]. The data was provided in the format of an ESRI Geodatabase. The contour information from the database was extracted into shapefile format for further use (Figure 2-12). The contour interval is 1 m for the most densely populated areas. The area west of Sooke, and the Gulf Islands, have contour intervals which vary from 2 m to 20 m. This data was not used in the Project DEM. However, prior to delivery of the 2019 GeoBC raft Li AR, the contour information was used during the process of selecting the areas for detailed modelling.

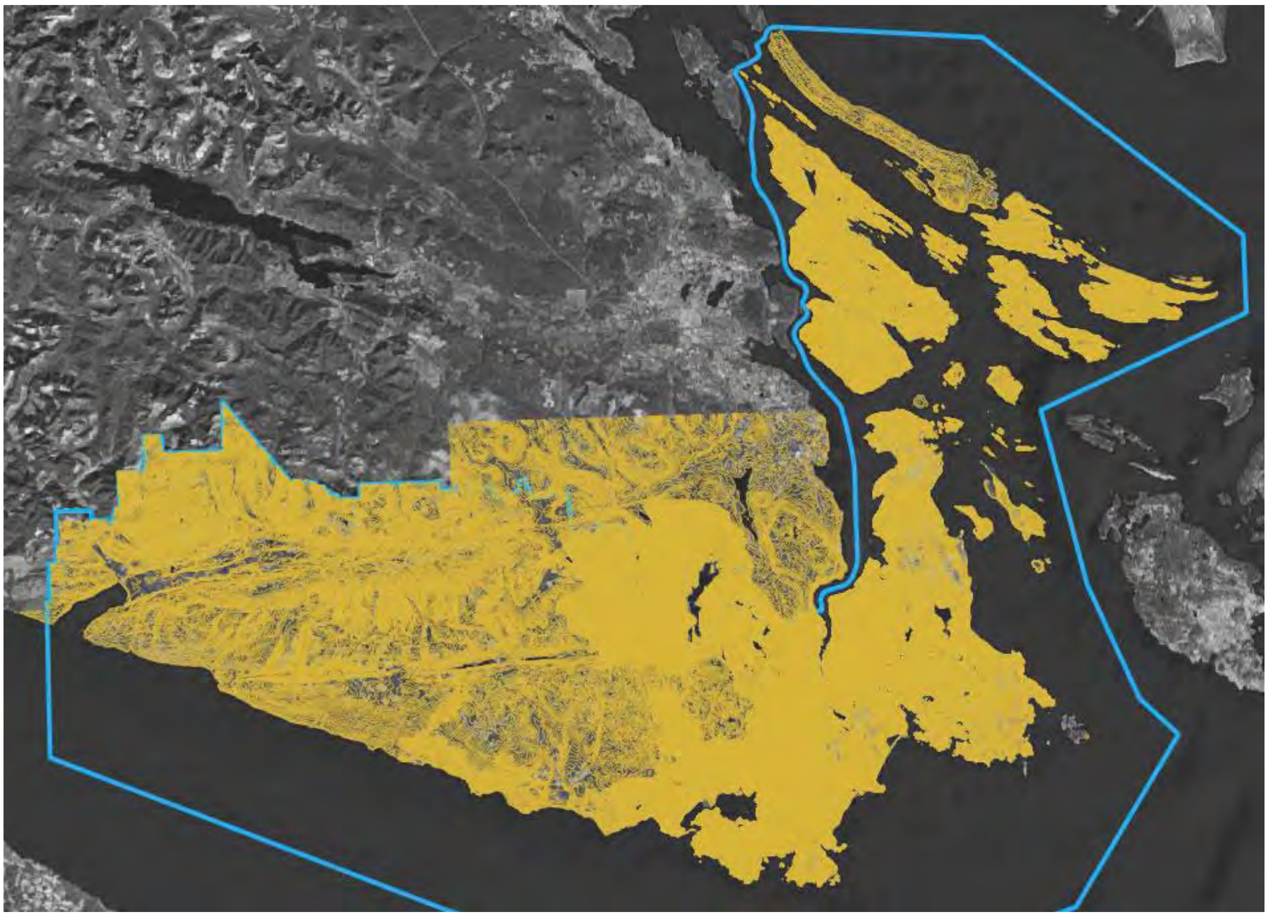

Figure 2-12
CRD Contour Data Coverage

[15] https://mapservices.crd.bc.ca/arcgis/rest/services/CRDcontours/MapServer/3

2.3.5 2013 CR Li AR

The CR provided 2013 Li AR data, which is used under a data use agreement. Included in the data are raster tiles (.tif format), 0.5 m contours (.shp format), and the Li AR point clouds (.las format). The data covers the majority of the Saanich Peninsula, as shown in igure 2-13. This data was not used for the Project M, as the 2019 GeoBC raft LiDAR is more recent and covers the entire study area. The 2013 CRD LiDAR was used to inform QA checks on the 2019 GeoBC Draft LiDAR, as described in Section 3.2.5.

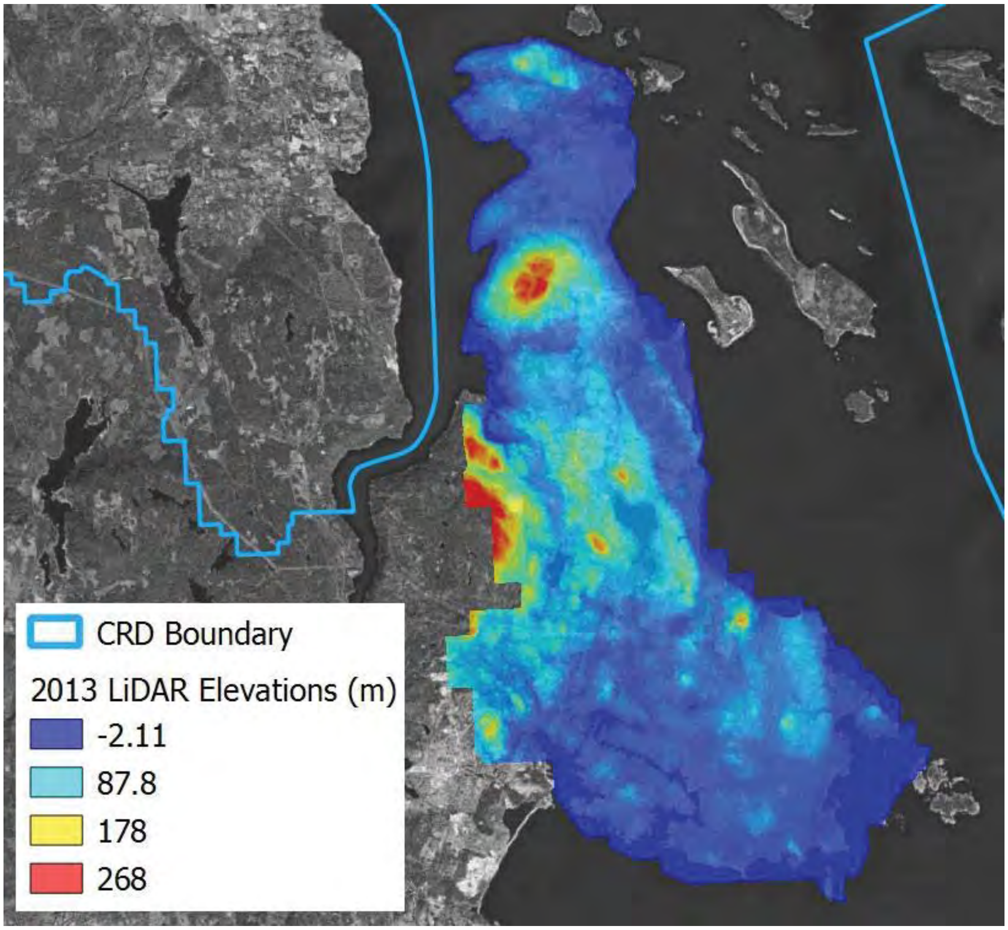

Figure 2-13
CR 2013 Li AR Coverage

2.3.6 Gulf Island Li   AR

The CRD provided an existing surface raster which covers the Gulf Islands area (Figure 2-14). The surface is a compilation of multiple datasets, with data from the University of Victoria, Parks Canada, and Island Trust. It has a grid resolution of 5 m. The vertical datum and information dates are unknown; the assumed vertical datum is CGV   28.

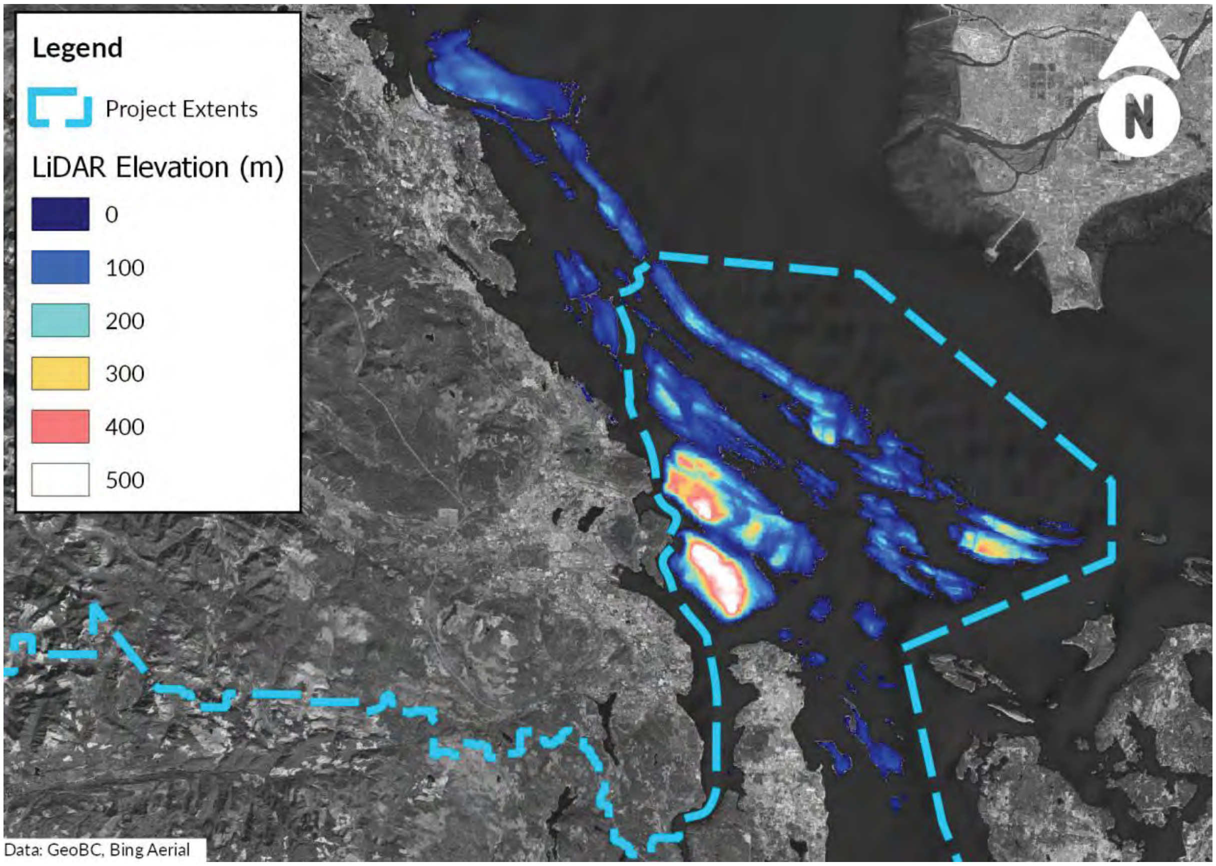

Figure 2-14
Gulf Island Li   AR Coverage

3 FINALIS D DIGITAL L VATION MO L

The Project M was developed to specifically meet the modelling and mapping requirements for this study. It includes bathymetric elevations for the majority of the Salish Sea, bounded by the western end of the Juan de uca Strait and topographic elevations for all land area near the coastline within the project study area (Figure 3-1).

The M was used in this study to:

- Define the bathymetric domain of the spectral wave model.
- Define the bathymetric and topographic domains for the transect analysis and detailed inundation models.
- Define the local-area bathymetric and topographic domains for the tsunami model.
- Prepare coastal flood mapping using the model results.

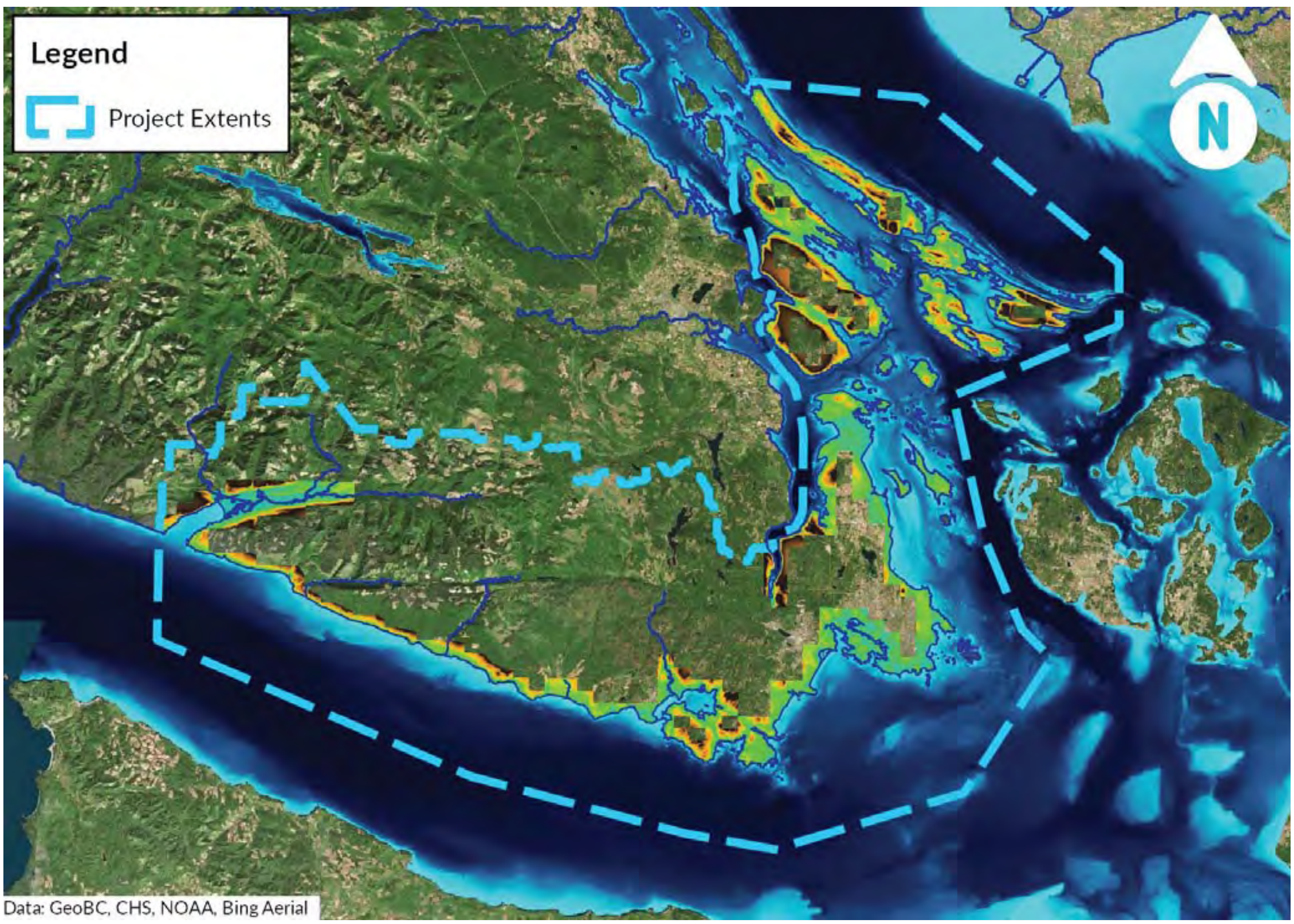

Figure 3-1
Project M: The Capital Region of British Columbia

As described in Section 2, multiple data sources comprise the final Project M. In this report the EM is discussed as a single item; in practice, it is separated in two parts for a simple reason. The bathymetric surface contains the detail of the sea floor, and the topographic surface contains the details of the land surface. The two datasets are combined when generating 2D area domains for the individual model inputs. Figure 3-2 graphically summarizes the process. Detailed descriptions of how each model utilizes the Project DEM are included in the Task 2 (Sea Level Rise Modelling & Mapping) and Task 3 (Tsunami Modelling & Mapping) reports.

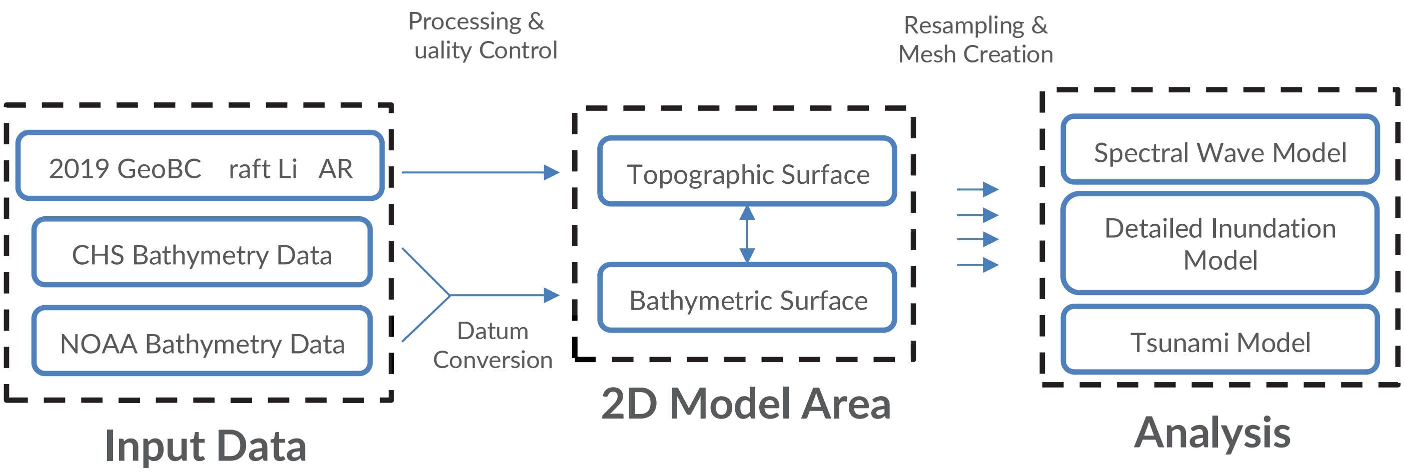

Figure 3-2
Project M Creation Process

3.1 Bathymetric Surface Processing

The bathymetric surface is primarily defined using the CHS 5 m data. Wherever there were gaps in the CHS dataset, it was supplemented with the NOAA 1/3 and 3 arc-second data to create a complete surface. The methodology for the bathymetric surface creation is described in the following steps:

1. Converted the CHS data from Chart Datum to CGVD2013.
2. Processed the CHS data into a raster grid with a resolution of $2 \bullet 10^{-4}$ deg, or approx. 22 m (see Section 3.1.2 for notes regarding the resolution and use of this raster grid).
3. Filled gaps in the CHS grid with NOAA ata.

3.1.1 Datum Conversion

The CHS bathymetric data has chart datum as the vertical reference. To maintain consistency for the entire project M, the elevations were converted to reference the CGV 2013 vertical datum. As described in Section 2.2, this conversion is not constant – it varies geographically. To make the conversion, CHS provided a text-file based grid (formatted as longitude/latitude/conversion) which covers the geographical extents of the dataset. These conversions were applied to the CHS bathymetry data.

The NOAA bathymetric grid references the Mean Sea Level (MSL) vertical datum, which is approximately equal to CGVD28. The difference between CGV 28 and CGVD2013 varies throughout the study area, but is generally less than 0.3 m. For spectral wave modelling, this minor difference in bathymetric elevation relative to the sea depth in the study area (e.g. 100 m) does not impact the results. This was proven by a test MIKE21 SW simulation, completed as part of Task 2 of this project[16]. Therefore, no conversions were applied to convert to NOAA elevations from MSL to CGV 2013. Similarly, for tsunami modelling in Task 3, this difference in bathymetric elevation is negligible, relative to the overall uncertainty in the modelling of tsunami generation and propagation.

3.1.2 Raster Grid Creation - Bathymetry

A custom interpolation program was used to create the raster grid. The program is a ‘stripped down’ version of the Bathymetry ditor in MIKE Zero. The code uses bilinear interpolation from a scatter dataset in x,y,z format to determine the bed elevations at the nodes of the user-defined grid. The user selects the position of the origin (coordinates of the lower left grid node) and the grid resolution; the grid orientation is always coincident with projection North. Geographical or UTM projections can be used; the first option was adopted since the CHS bathymetry data was provided as Longitude, Latitude, Elevation relative to CD (chart datum).

The user also defines the search radius (as a multiple of the cell size) within which the code searches for a maximum of four points to be used in the bilinear interpolation. The larger the search radius, the greater the potential for the bed elevation at a given cell node to be influenced by scatter points located relatively far away. In order to prevent this from occurring as much as possible, a search radius equal to 1 grid cell (22 m) was adopted.

The raster grid was converted to DHI Software proprietary grid format S2 using conversion tools available in the software package and used as input for the generation of the mesh and bathymetry for the spectral wave model MIKE 21 SW. Direct use of the CHS bathymetry dataset for interpolation of bed elevations onto the unstructured model mesh is not feasible due to the very large number of soundings in the dataset. The 22 m grid should therefore be seen as just an intermediate step in the processing of bathymetry data and model mesh generation. The 22 m grid was never directly used in the spectral wave modelling.

Please note that the processed bathymetric raster grid resolution of 22 m is obviously coarser than both the parent 5 m CHS data, and NOAA 1/3 arc-second data, but much finer than the resolution of the MIKE 21 SW unstructured mesh. Transects, however, are extracted at the original CHS resolution of 5 m to preserve optimum bathymetric fidelity. Bathymetries for tsunami and detailed modelling were also interpolated from the LiDAR and CHS bathymetry datasets. urther information on these processes are contained within the Task 2 (Sea Level Rise Modelling & Mapping) and Task 3 (Tsunami Modelling & Mapping) reports.

3.1.3 Gap Filling

The CHS bathymetry data was given higher priority than the NOAA DEMs when using the Mesh Generator to interpolate the bed elevations into the nodes of the unstructured mesh that MIK 21 SW uses as bathymetry. The option to prioritize datasets is a standard feature of the Mesh Generation and eliminates the need to combine several datasets into one prior to generating the mesh. In this particular case, prioritization means that CHS data were used whenever possible; only in areas not covered by the CHS bathymetry were bed elevations from the NOAA datasets used.

[16] The test involved simulating a full calendar year in the Task 2 MIKE 21 SW model. The model simulation increased the depth of the water column by 2m (to mimic 2m sea level rise), which resulted in negligible increases in wave height. or further information on this, please refer to Task 2 (Sea Level Rise Modelling & Mapping) Report.

3.2 Topographic Surface Processing

The topographic surface for the project DEM is defined using the 2019 GeoBC raft Li AR data, provided under licence by GeoBC. At the time of this study, the fully processed data was not yet available. As described in Section 2.3, .laz point clouds were provided with preliminary point classification. The methodology for the topographic surface creation is described in the following steps:

1. Visually reviewed the data for any issues or inconsistencies.
2. Converted the point cloud data to a raster grid with a resolution of 1 m for the project area extents.
3. Prepared additional individual raster files for the detailed modelling areas.
4. Trimmed LiDAR data at the approximate low-water elevation to remove water-surface elevations from the topographic surface.
5. Performed a quality control check on the 2019 GeoBC raft Li AR raster data using 2013 LiDAR as a comparative tool. This occurred prior to the modelling tasks. At the end of the project, when it became available, the 2019 GeoBC inal Li AR data was used as an additional quality control check.

The raster created from the 2019 GeoBC raft Li AR data, which makes up the topographic portion of the project M, is shown in igure 3-3.

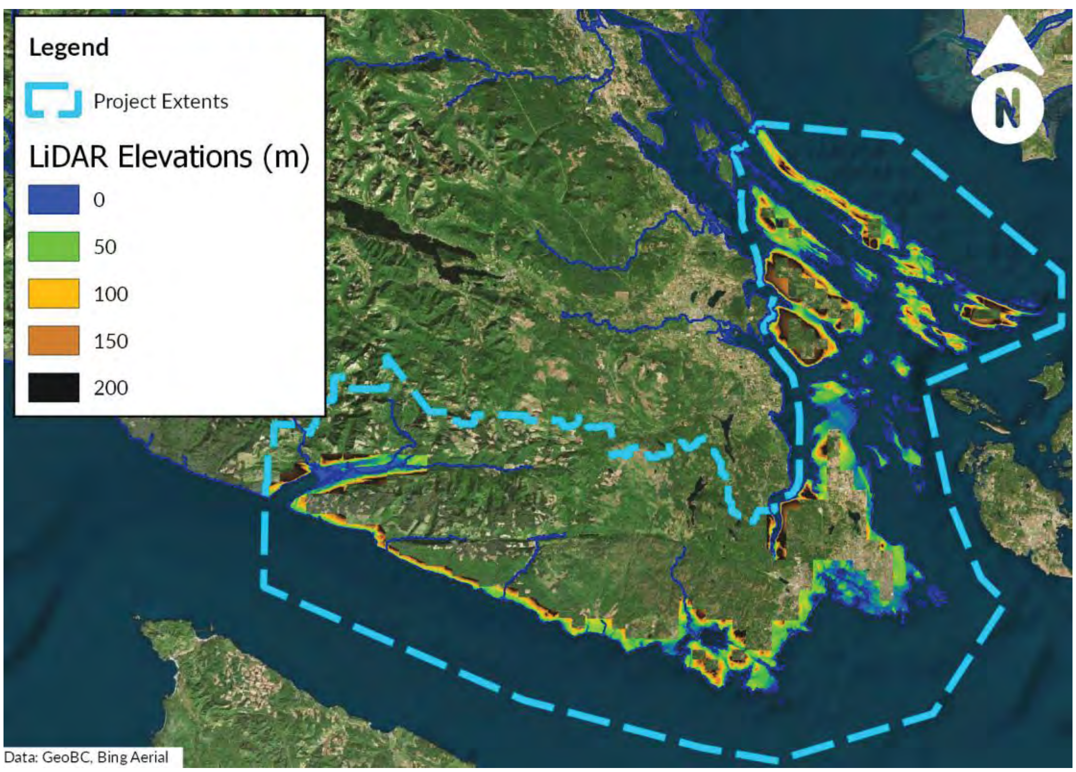

Figure 3-3
Project M: Topographic Surface

3.2.1 Visual Review

As the 2019 GeoBC raft Li AR data was preliminary in nature, it was reviewed and quality-control checked to ensure that the quality was fit for use in the project DEM. The quality of the data was fit for use in this study, with limitations detailed in Section 3.3.

As an initial high-level check of the data, the point cloud tiles were reviewed in a variety of locations within the study area. Three issues with the data were observed.

Observation: There are artefacts in the data which are incorrect. As shown in Figure 3-4, there are points with elevations in the range of -10,000 m to 10,000 m.

Solution: The points were filtered to remove these extreme values. Only points between -10 m and 200 m elevation were kept.

Figure 3-4
LiDAR Point Cloud Artefacts

Observation: ach point in the data is assigned one of two classifications: “unclassified” or “ground”. As the modelling required a bare-earth surface, the unclassified points were filtered out (Figure 3-5). As expected, this removed elevation points which correspond to buildings or vegetation. However, there were hard-surface areas which were missing (i.e. remain “unclassified”).

Solution: Within the detailed model areas any “unclassified” points were reclassified as “ground” which are needed to create an accurate representation of the ground surface.

Figure 3-5
LiDAR “Ground” Points Only

Observation: Points reflecting off the water surface have been classified as "ground". In a fully classified point cloud, water points would be classified separately to allow them to be filtered out to create the elevation raster.

Solution: After creation of the topographic M from the point cloud data, the raster was trimmed at the assumed coastline to remove any water surface elevation data.

Figure 3-6 shows the point cloud tiles in the Victoria Harbour, and McNeil Bay detailed modelling areas, with the two filters described above: unclassified points have been filtered out, and extreme point elevations have been restricted to exclude artefacts.

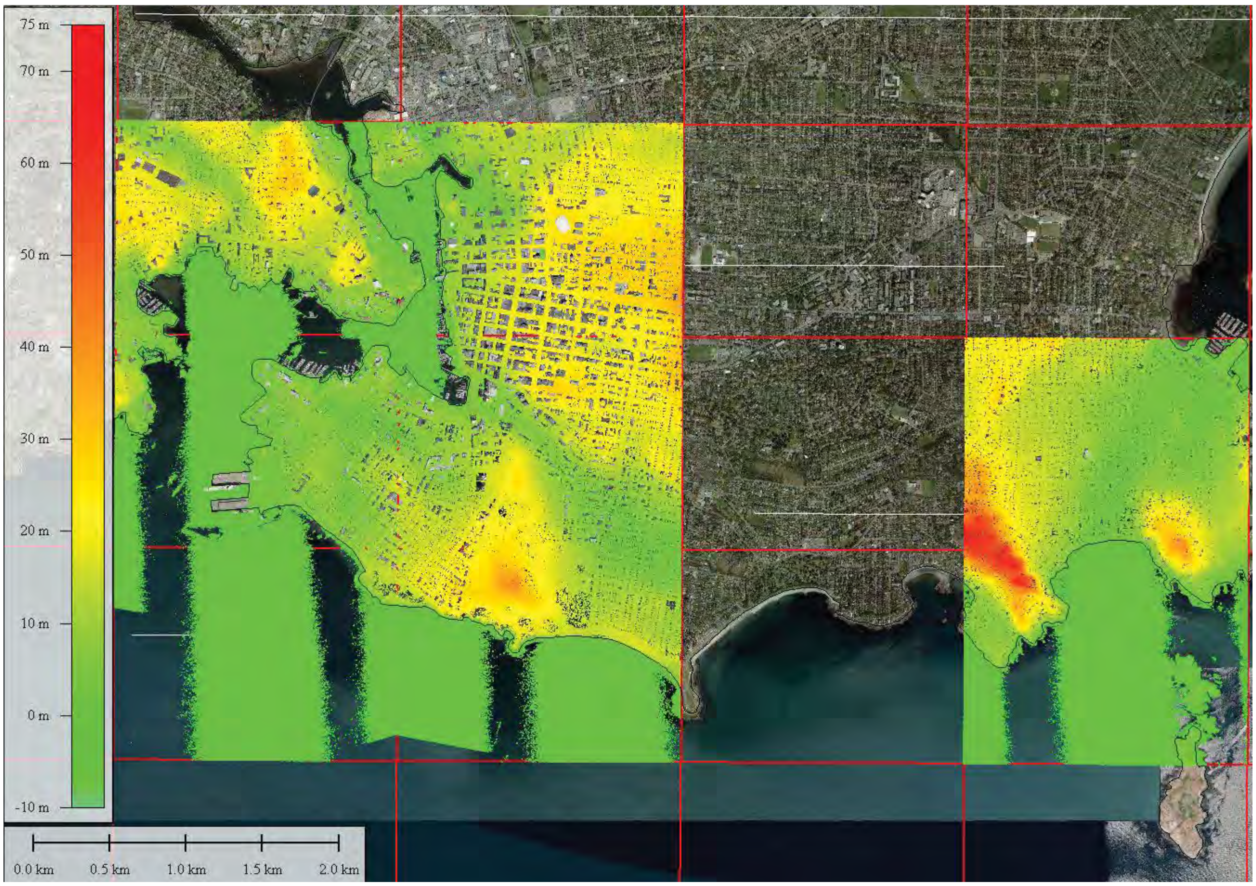

Figure 3-6
LiDAR Point Cloud Sample (iltered)

3.2.2 Raster Grid Creation - Topography

This section details the methods used to transform the point cloud data into rasters to be used in the Project M. The software used for this task are Global Mapper v21.0 (for creation of the grids) and GIS v3.4 (for filling gaps in the surfaces).

The entire 2019 GeoBC raft LiDAR dataset included detail outside of the project study area. As converting the point cloud files to rasters is a computationally intensive task, the data set was pared down to only the required areas. Any tiles outside of the project study area, in open water, or far inland from the coastline were excluded. Figure 3-7 shows the selected tiles (536) relative to the overall dataset (1037).

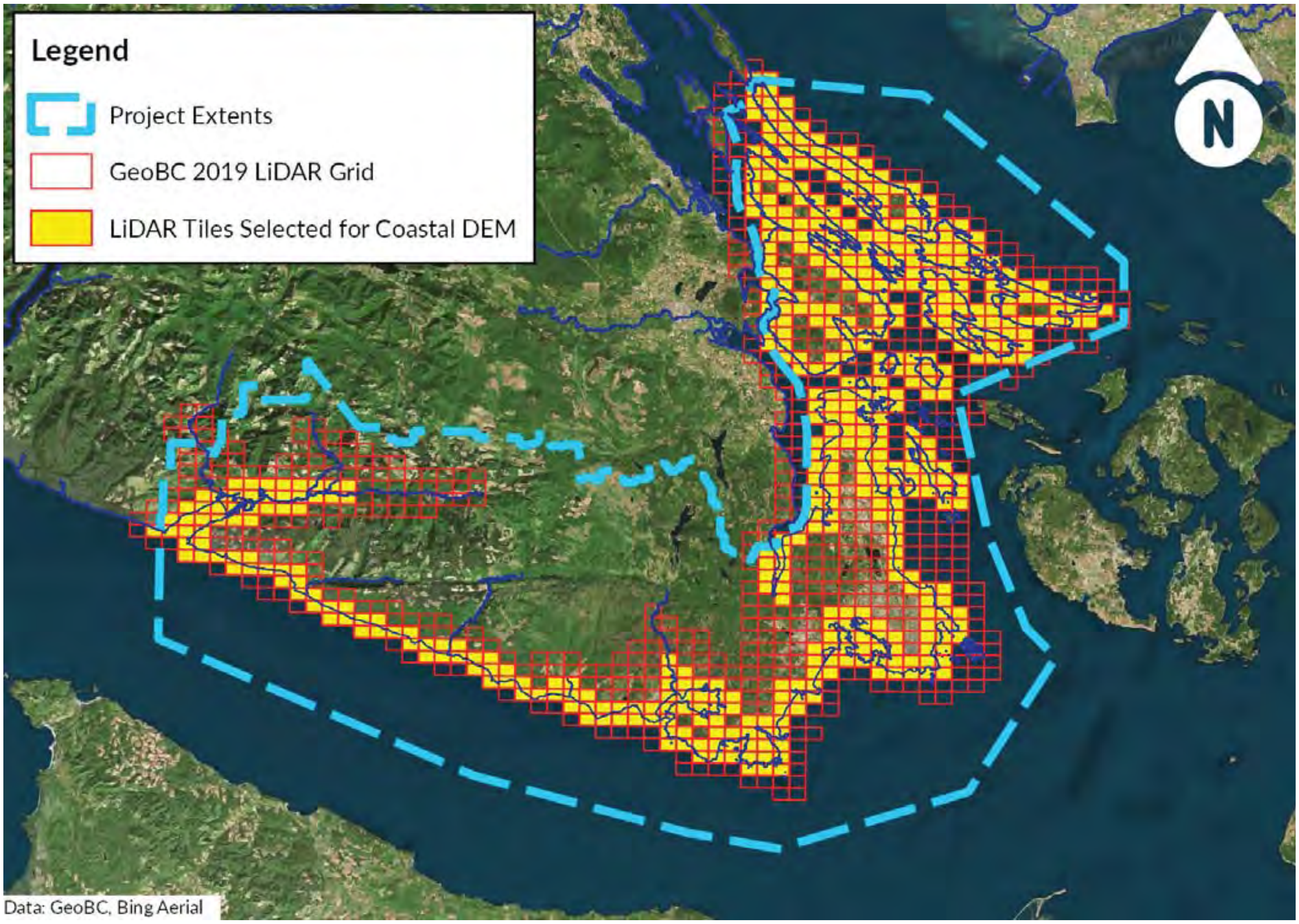

Figure 3-7
GeoBC Li AR Tiles used for D M

To create the raster files, it was necessary to subdivide the selected files into smaller groups – roughly 25-40 tiles each. Each group was loaded into Global Mapper using the filters described above. Once loaded, the data was gridded using a triangulation method and exported to a .tif format raster. xporting to a .tif interpolates the triangulated data and gives a representative elevation value for each raster grid cell. A grid cell size of 1 m was selected, which is typical for LiDAR surface datasets and appropriate for the level of detail required for the inundation models.

Since the raster at this stage is only based on "ground" points, there are gaps wherever a building exists. While the export process is able to interpolate over small gaps in data, some larger gaps still need to be filled. Figure 3-8 shows the exported raster with data gaps for the area near Victoria Harbour. igure 3-9 shows the same raster after filling gaps. The SAGA "Close Gaps" tool[17] was used to achieve this, which is a nearest-neighbour interpolation method.

[17] http://www.saga-gis.org/saga_tool_doc/2.2.6/grid_tools_7.html

It is important to note that LiDAR in general is not capable of capturing variances in elevation within buildings (e.g. basements, staircases etc.) Therefore, LiDAR values within building footprints tend to be informed by ground points at the building edges.

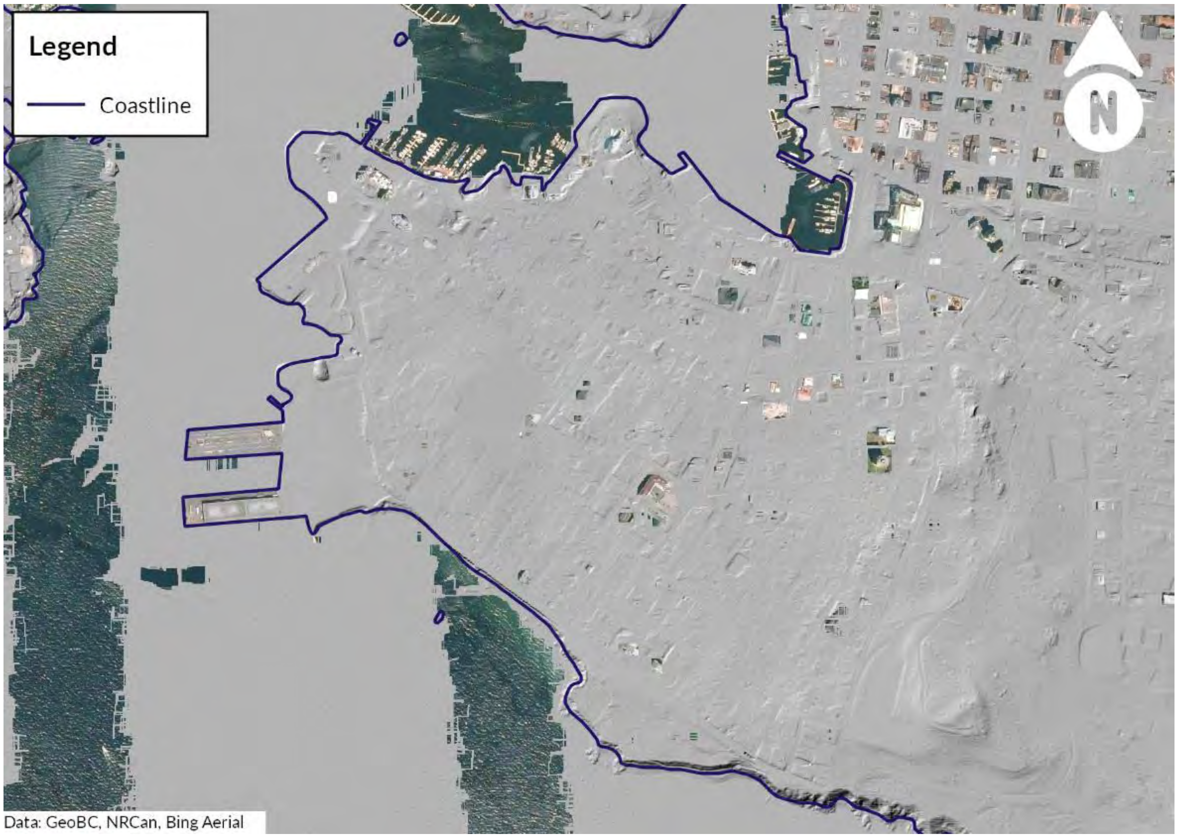

Figure 3-8
Raw LiDAR Raster

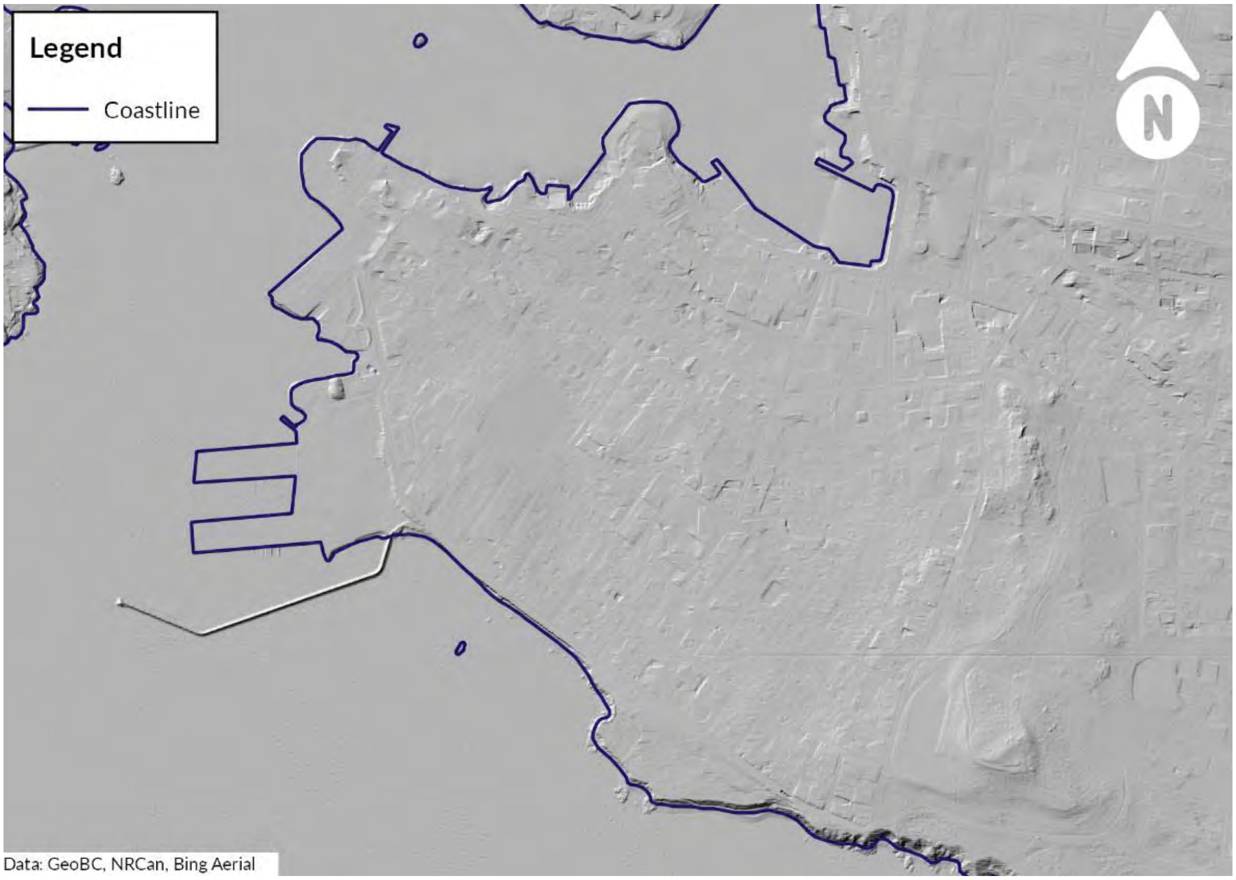

Figure 3-9
LiDAR Raster with Gaps Filled

3.2.3 Detailed Modelling Areas

Based on the observations previously noted in the detailed model areas, some additional edits were required to prepare the raster for detailed modelling. Several important hardscape features were not classified as "ground" points, and as such, were excluded from the raster process detailed above. The raster was manually edited to include these features, as explained below.

At Victoria Harbour, several piers were not classified properly. The raster was manually edited based on the point cloud elevations to include these. igure 3-10 shows the aerial view of the harbour, igure 3-11 shows the raw exported raster, and Figure 3-12 includes the manual edits and gap filling.

The terminals and breakwater at Ogden Point in Victoria were also classified incorrectly, and the same process was followed to edit the raster to include these features. This is presented in igures 3-13 through 3-15.

Lastly the drydocks and piers in Esquimalt were manually defined. igure 3-16 presents the final topographic raster in this area.

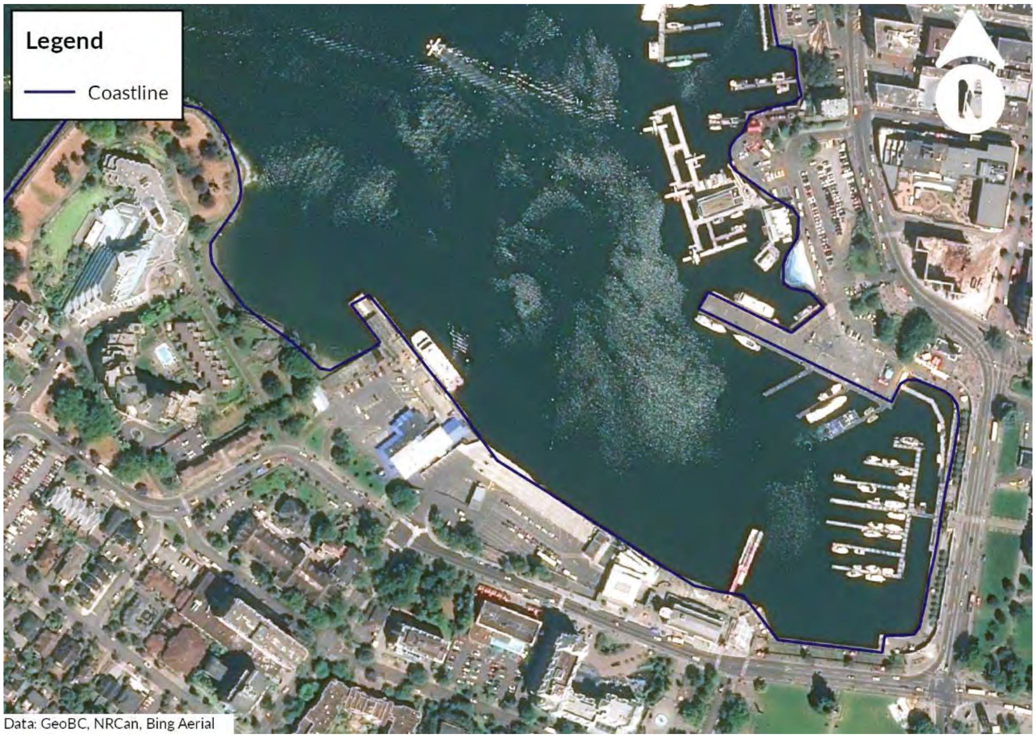

Figure 3-10
Victoria Harbour Aerial View

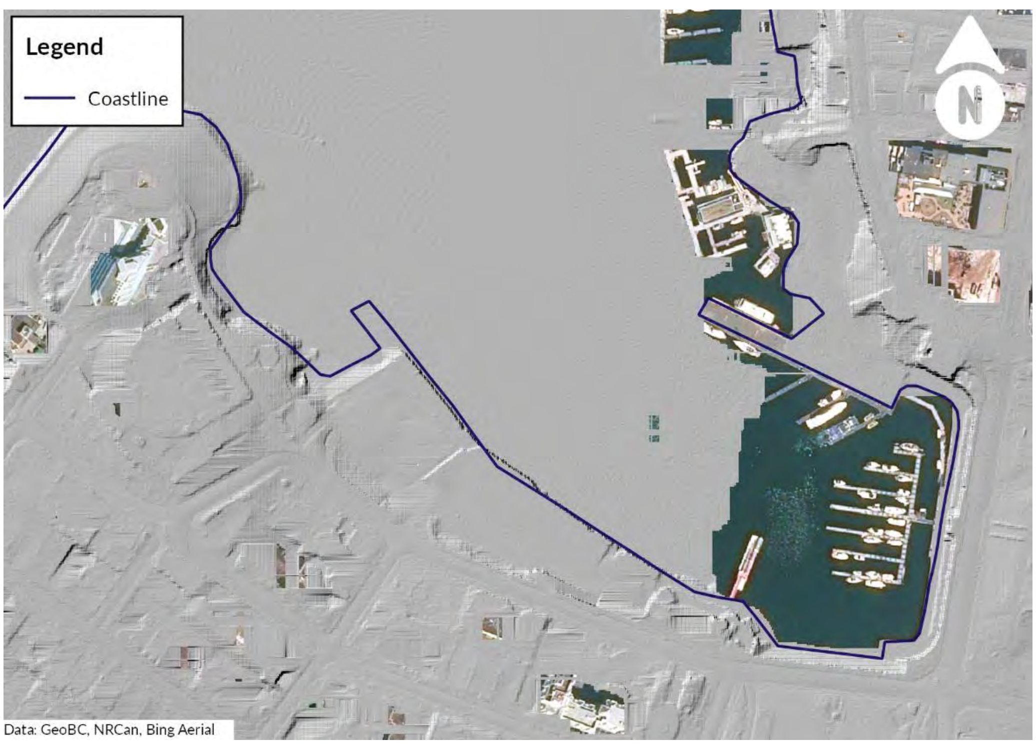

Figure 3-11
Victoria Harbour Raw Raster (note: lack of definition of piers)

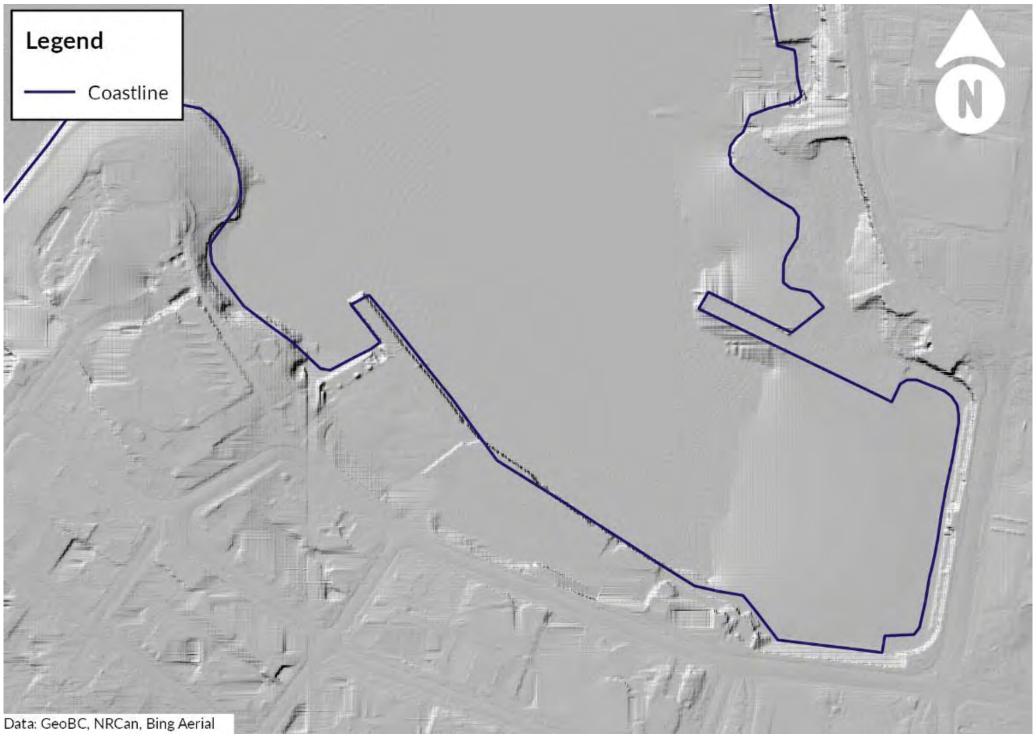

Figure 3-12
Victoria Harbour Raster including dits and Gaps illed

Figure 3-13
Ogden Point Terminals and Breakwater Aerial View

Figure 3-14
Ogden Point Raw Raster (note: lack of definition of terminals and breakwater)

Figure 3-15
Ogden Point Terminals and Breakwater including Edits and Gaps illed

Figure 3-16
squimalt Harbour rydocks including dits and Gaps illed

3.2.4 Remove Water Surface levations

As explained in Section 2.3, the 2019 GeoBC raft Li AR point cloud data includes water surface elevations classified as ground points. To complete the detailed coastal modelling, it was necessary to trim the topographic surface at the land/sea boundary to remove any water surface elevations from the project DEM. The goal through this process was to preserve as much of the ground surface data as possible. The position of the land/sea boundary is dependant on the tide level at the time of the LiDAR survey; at high tide there is less exposed ground than at low tide. Generally, the Li AR survey flights occurred during low-tide periods to capture as much of the intertidal zone as possible.

To remove the water surface points, the M was manually trimmed using three methods, depending on the level of detail required in each area.

1. **etailed Modelling Areas:** Manually trimmed the topographic surface based on the visible transition in the raw LiDAR raster between land and sea.
2. **Transect Analysis Areas:** Trimmed the topographic surface along contour lines extracted from the surface. The contour elevations were chosen to be as close as possible to the land/sea transition, to preserve as much ground elevation as possible. Contour elevations ranged from -0.6 m to -1.2 m, depending on the water level during the Li AR survey across the project area.

3. **Small Off-Shore Islands:** or small off-shore islands the CanCoast Marine Shoreline v3.0[18] (NRCAN, 2019) was used. This dataset was developed by NRCAN from CanVec 9.0, an existing public digital data source derived from 1:50,000 scale topographic maps. The CanCoast shoreline polyline is approximately equal to the high-water line and is suitable for use in areas where high resolution is not needed (i.e., small rocky offshore islands which should be included in the model domains, but where detailed inundation results are not required).

Figure 3-17 illustrates the topographic surface trimming process within a detailed modelling area (McNeill Bay). The raw raster on the left and the elevation profile (red line) show the clear transition between the sloping beach and the flat water surface. The cyan line is the manually defined trimming line, based on the land/sea transition. The dark blue line is the CanCoast polyline, shown for reference. The trimmed result, on the right, is the final trimmed topographic surface which is part of the project DEM.

[18] https://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=314669

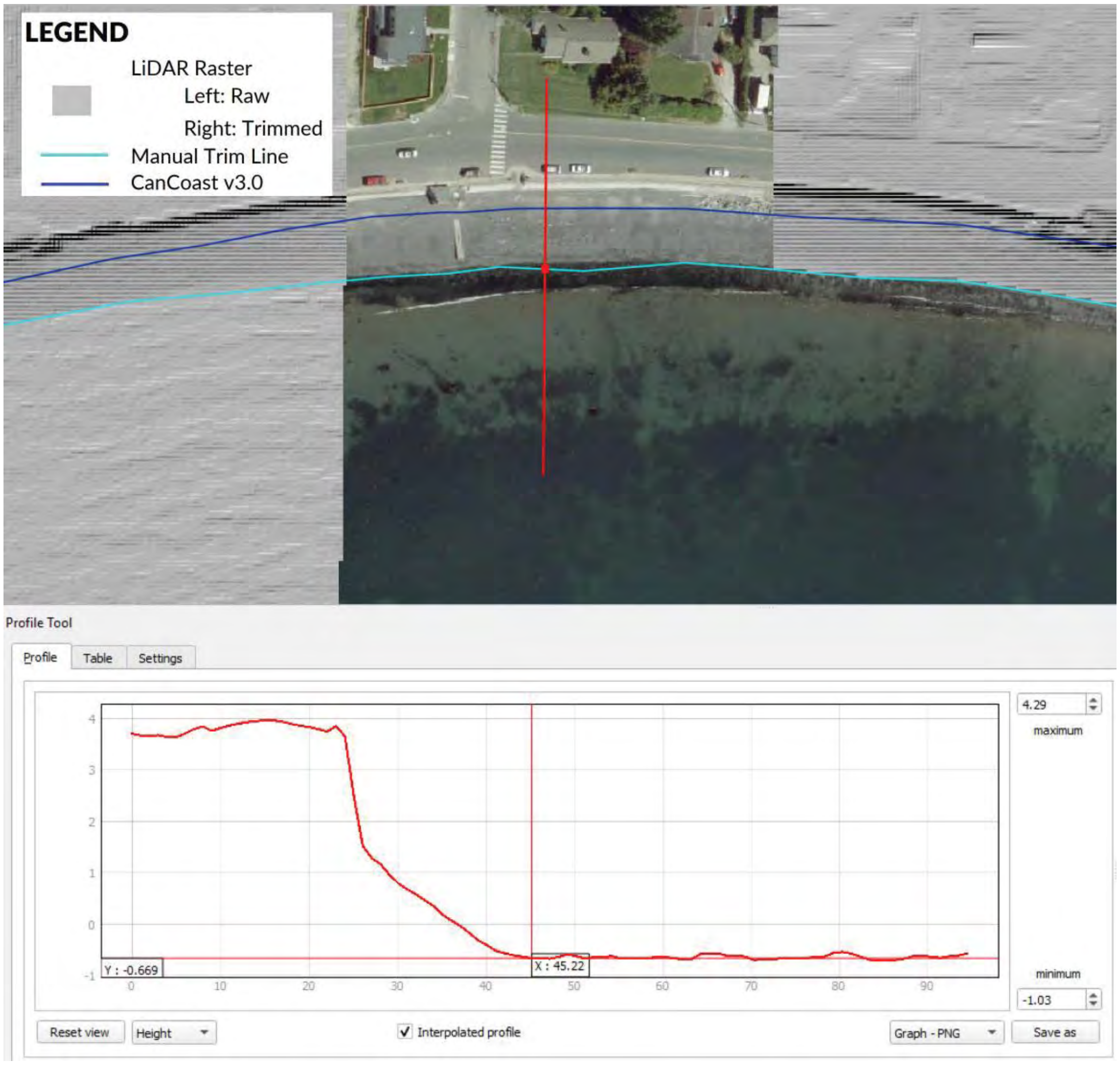

Figure 3-17
Topographic Surface Trimmed at Edge of Water

3.2.5 levation Quality Control

The final step in the raster creation was a quality control check on the elevation data itself. Elevations from the 2019 GeoBC Draft LiDAR data (i.e. the topographic portion of the Project DEM) were compared to the previously published 2013 Li AR elevation data. If calibrated properly, the two datasets should report similar elevations at any given grid cell. Some variation is expected based on the grid cell resolution and Li AR survey itself.

To compare elevations, several hardscaped areas which do not appear to have had any land changes (i.e. grading or development) between 2013 and 2019 were selected. The average elevation of a 10 m x 10 m polygon in each of these areas was sampled and the results were compared. As the 2013 Li AR surface references the CGV 28 datum, conversions were applied as calculated using the NRCan web app (see Section 2.2). The results are shown in Table 3-1.

Table 3-1
levation uality Control for Greater Victoria Area - CGV 28 to CGV 2013 Conversion

Location	Average Difference Between 2013 Li AR and Project M	Conversion (CGV 28 to CGVD2013)	Actual Average ifference Between 2013 Li AR and Project DEM
Central Saanich	139 mm	134 mm	5 mm
Esquimalt	212 mm	159 mm	53 mm
North Saanich	156 mm	122 mm	34 mm
Oak Bay	100 mm	146 mm	46 mm
Saanich	208 mm	149 mm	59 mm
Sidney	203 mm	128 mm	75 mm
Victoria	214 mm	156 mm	58 mm
View Royal	166 mm	155 mm	11 mm

For elevation quality control in the Gulf Island region, the CRD provided an additional existing surface raster which covers the islands, as detailed in Section 2.3. The surface is a compilation from multiple datasets and has a grid resolution of 5 m. The vertical datum and information dates are unknown. or this comparison, it was assumed that the surface references the CGVD28 vertical datum. Using the same method as above, this surface was compared to the Project DEM (Table 3-2).

Table 3-2
levation uality Control for Gulf Islands - CGV 28 to CGV 2013 Conversion

Location	Average Difference Between Existing Surface and Project DEM	Conversion (CGV 28 to CGVD2013)	Actual Average ifference Between the xisting Surface and Project M
ulford Harbour (Salt Spring Island)	1234 mm	121 mm	1113 mm
Ganges (Salt Spring Island)	-161 mm	109 mm	-270 mm
North Pender Island	240 mm	88 mm	152 mm
Sturdies Bay (Galiano Island)	280 mm	70 mm	210 mm

The difference in elevations between the existing surface and the Project M for the selected areas within the Gulf Islands is quite varied, especially compared to the Greater Victoria Area (Table 3-1). However, due to the coarse resolution, unknown data origins, and unknown vertical datum of the Gulf Island surface, it cannot be concluded that these differences indicate an issue/problem with the Project M.

3.2.6 Subsequent Elevation Quality Control – 2019 GeoBC Final LiDAR

The 2019 GeoBC Final LiDAR bare-earth model (DTM in ASCII format) became available near the end of the project. This occurred during the final reporting period and after all modelling tasks were completed. As a final quality control check, the 2019 GeoBC Final LiDAR model was compared with the 2019 GeoBC Draft LiDAR model created by the project team. A variety of locations throughout the capital region were selected, in keeping with the methodology for the previous checks detailed in Section 3.2.5. The results are presented in Table 3-3.

Table 3-3
Elevation Quality Control for Capital Region – 2019 GeoBC Draft and Final LiDAR

Location	Average Difference between Final and Draft 2019 GeoBC LiDAR Surfaces
North Pender	11.5 mm
Sturdies Bay	7.4 mm
Ganges	9.9 mm
Fulford Harbour	-7.8 mm
North Saanich	-13.8 mm
Sidney	-4.4 mm
Central Saanich	-13.1 mm
Saanich	8.4 mm
Oak Bay	-14.9 mm
Victoria	5.3 mm
Esquimalt	3.4 mm
View Royal	7.7 mm

Location	Average Difference between inal and Draft 2019 GeoBC LiDAR Surfaces
Sooke Road	-10.3 mm
Cheanuh Marina	4.3 mm
Metchosin Road	-6.9 mm
HWY14_Jordan River Campground	-6.4 mm
Port Renfrew Pacific Gateway Marina	-3 mm
Port Renfrew Marina Rd	-4.5 mm
Sooke Silver Spray Rd	-20.2 mm
Sooke HWY14	20.7 mm
rench Beach	1.9 mm

Notes:

- A positive value indicates the 2019 GeoBC inal Li AR surface has a greater elevation than the 2019 GeoBC raft LiDAR surface.
- The average absolute difference across all selected locations is 8.8 mm.
- The maximum difference observed across all selected locations is 20.7 mm.

3.3 Limits of Use

The 2019 GeoBC Draft LiDAR surface is fit for use for the purpose of the Coastal Flood Inundation Mapping Project, as confirmed by the final quality control check with the 2019 GeoBC Final LiDAR surface. However, there are certain limitations which are noted below.

- At the outset of the project, the project team expected to receive the LiDAR data from GeoBC in November 2019. Receipt of the data was delayed until late January 2020, and the data received was not fully classified or quality controlled. Additionally, artefacts and mis-classified points were encountered in the data. As such, the rasters that were prepared for this project should be considered preliminary in nature and differ slightly from the final product produced by GeoBC. It is also important to note that the 2019 GeoBC raft LiDAR processed in this project should not be used for any other projects or purposes.
- The DEM was manually edited in several areas (as in the sections described above) to fix issues with incorrect classifications. These edits are a less accurate reflection of the actual surface than the properly classified data.
- LiDAR points that reflect off water should be classified as "water" and filtered out of the data, such that the surface only includes points on the ground. However, the preliminary data classified all points on water as "ground", which introduces inaccuracy and difficulty in defining the boundary between bathymetry and the ground surface. The DEM was manually trimmed at the assumed land/sea boundary. This resulting DEM is sufficient for the project modelling tasks, but does not represent the ground surface as well as properly classified base LiDAR data would allow.

CERTIFICATION PAGE

This report presents our work for Task 1 – EM evelopment regarding the Capital Region oastal Flood Inundation Mapping Project. The services provided by Associated Engineering (B.C.) Ltd. in the preparation of this report were conducted in a manner consistent with the level of skill ordinarily exercise by members of the profession currently practicing under similar conditions. No other warranty expressed or implied is made.

Respectfully submitted,

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