CITY OF VANCOUVER

CITY CLERK'S DEPARTMENT
Access to Information & Privacy Division

File No.: 04-1000-20-2022-067

June 1, 2022

s.22(1) [redacted]

Dear s.22(1) [redacted]

Re: **Request for Access to Records under the Freedom of Information and Protection of Privacy Act (the "Act")**

I am responding to your request of February 8, 2022 under the ***Freedom of Information and Protection of Privacy Act, (the Act),*** for:

> **Planning studies completed after February 1, 2019 related to the Central Waterfront, specifically:**
> 1. **Sea Level Rise study;**
> 2. **Baseline Economics study; and**
> 3. **Dangerous Goods study.**

All responsive records are attached. Some information in the records has been severed, (blacked out), under s.17(1) of the Act. You can read or download this section here: http://www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/96165_00.

Please note, there are no responsive records in relation to point three of your request; the Dangerous Goods study has not been completed.

Under section 52 of the Act, and within 30 business days of receipt of this letter, you may ask the Information & Privacy Commissioner to review any matter related to the City's response to your FOI request by writing to: Office of the Information & Privacy Commissioner, info@oipc.bc.ca or by phoning 250-387-5629.

If you request a review, please provide the Commissioner's office with: 1) the request number (#04-1000-20-2022-067); 2) a copy of this letter; 3) a copy of your original request; and 4) detailed reasons why you are seeking the review.

City Hall 453 West 12th Avenue Vancouver BC V5Y 1V4 vancouver.ca
City Clerk's Department tel: 604.829.2002 fax: 604.873.7419

Yours truly,

[Signed by Cobi Falconer]

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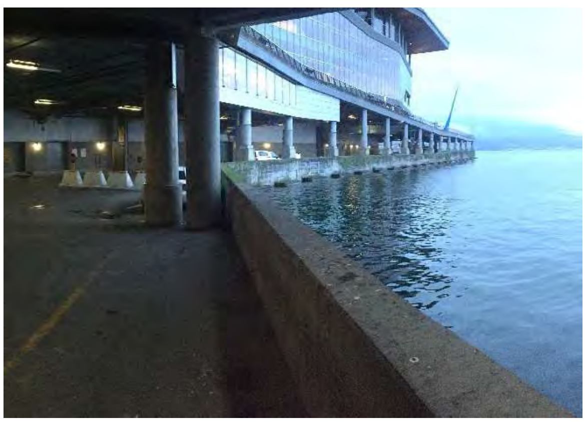
If you have any questions, please email us at foi@vancouver.ca and we will respond to you as soon as possible. Or you can call the FOI Case Manager at 604-871-6584.

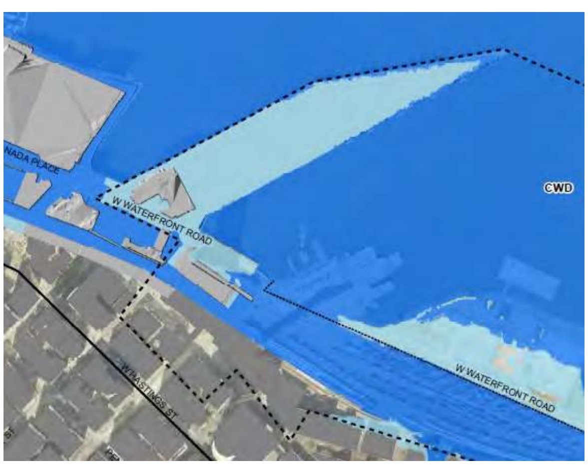
Encl. (Response Package)

:ku

CENTRAL WATERFRONT DISTRICT

TOPOGRAPHIC SURVEYS, GIS, AND FLOOD RISK MODELLING PROJECT





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Final Report: August 26, 2019

NHC Ref. No 3004609

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CENTRAL WATERFRONT DISTRICT TOPOGRAPHIC SURVEYS, GIS, AND FLOOD RISK MODELLING PROJECT

FINAL REPORT

Prepared for:

Vancouver Fraser Port Authority
Vancouver, BC

Prepared by:

Northwest Hydraulic Consultants Ltd.
North Vancouver , BC

26 August 2019

NHC Ref No. 3004609

nhc

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DISCLAIMER

This report has been prepared by **Northwest Hydraulic Consultants Ltd.** for the benefit of **Vancouver Fraser Port Authority** for specific application to the **Central Waterfront District Topographic Surveys, GIS, and Flood Risk Modelling Project**. The information and data contained herein represent **Northwest Hydraulic Consultants Ltd.** best professional judgment in light of the knowledge and information available to **Northwest Hydraulic Consultants Ltd.** at the time of preparation, and was prepared in accordance with generally accepted engineering practices.

Except as required by law, this report and the information and data contained herein are to be treated as confidential and may be used and relied upon only by of **Vancouver Fraser Port Authority**, its officers and employees. **Northwest Hydraulic Consultants Ltd.** denies any liability whatsoever to other parties who may obtain access to this report for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this report or any of its contents.

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EXECUTIVE SUMMARY

Northwest Hydraulic Consultants Ltd. (NHC) conducted a sea level rise (SLR) and flood risk assessment of the Central Waterfront District for the Vancouver Fraser Port Authority (VFPA). The study examined present day flood risks due to high tides and storm surge, and how these risks may change with future SLR. The study was undertaken to integrate with existing mapping previously done for the City of Vancouver (CoV) and aid the VFPA and the CoV in planning for future flood mitigation needs in the Central Waterfront District. The study used a combination of aerial LiDAR and terrestrial LiDAR collected in 2018 / 2019 for this study to build a Digital Elevation Model (DEM) to represent the topography in the study area. Four scenarios representing a combination of SLR and storm surge return periods were modelled.

Utilizing the model outputs NHC has prepared maps showing flood depths and extents. A hazard analysis was also undertaken to characterize the flooding, examine the likely disruption and damage effects of the flooding on the infrastructure and assets in the area, and suggest mitigations. The modelling found SLR to be the main factor which influenced the flood depths. In the models, ingress of flood waters into the study area tends to occur at three consistent points of varying elevation:

- Southwest corner of the SeaBus Terminal parking lot (approximate El. 2.9 m);
- The low point in the wall on the north side of Vancouver Convention Centre West (VCCW) (assumed El. 3.1 m); and
- The eastern edge of the Coal Harbour seawall at the Sea Plane walkway (approximate El. 3.4 m).

For present day conditions flooding is localized and relatively shallow, impacting mainly the area around the SeaBus Terminal (the non-floating portion on the land). With 0.5 metres of SLR, the SeaBus Terminal and nearby railyard are both impacted by flooding, and there is inundation through a low area on the VCCW wall which affects the lower level of VCCW. With 1.0 metre of SLR, flooding covers a significantly larger area including the SeaBus Terminal, the railyards, all sides of VCCW, much of Waterfront Road and connected underground parking structures, and potentially affects the SkyTrain tunnels. The extensive flooding and increasing flood depths start to increase wave and velocity hazards in this and the following scenario. In the final scenario with 1.6 metres of SLR, all areas flooded with 1.0 metres of SLR are also flooded as well as the lower level of Canada Place. As SLR increases, flood depth increases, and wave effects impact a larger area.

As the area is heavily developed and relies on waterfront access and water-based transportation for many of its functions, the main mitigations suggested are ‘hard’ protective measures including raising existing barriers and floodproofing infrastructure.

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1 INTRODUCTION

1.1 Purpose

Northwest Hydraulic Consultants Ltd. (NHC) was retained by the Vancouver Fraser Port Authority (VFPA) to conduct a sea level rise (SLR) and flood risk assessment of the Central Waterfront District. The purpose of the study is to provide information on present day flood risk due to high tides and storm surge, and how these risks may change with SLR. The study is intended to integrate with previously prepared mapping for the City of Vancouver (CoV) and aid the VFPA and the CoV in planning for future flood mitigation needs in the Central Waterfront District.

1.2 Project Background

It is expected that climate change will contribute to SLR and an increased occurrence of storm events over the coming decades, which will affect VFPA and CoV assets. In 2014, NHC completed a Coastal Flood Risk Assessment (CFRA) for the CoV to evaluate the vulnerability of the CoV shoreline due to high tides, storm surge, and SLR (NHC, 2014).

The 2014 CoV study found that Waterfront Road is vulnerable to flooding; however, limited topographic data was available for the section of Waterfront Road beneath Canada Place Way, and so the nature of the flooding was largely unknown. This study is intended to be an extension of the 2014 CoV study, with a focus on the underground section of Waterfront Road between Howe Street and Thurlow Street at the Convention Centre and Canada Place.

The scope of this study includes:

- Collection of outstanding topographic data along Waterfront Road and the development of an improved digital elevation model (DEM) of the Central Waterfront District.
- Development of a two-dimensional hydraulic model to better understand the flood hazard along Waterfront Road through analyzing four scenarios representing various storm and SLR combinations.
- An assessment of the flood risk to key assets in the Central Waterfront District in these scenarios.
- Recommendations for design requirements, infrastructure upgrades, and gaps requiring further study to address the identified risks and support future development potential in the area.

1.3 Site Description

The Central Waterfront district is a focal point of the downtown area with a mixture of land uses and has significant tourist, transportation and business infrastructure. The area borders downtown Vancouver to the South, and Burrard Inlet to the north (See Figure 1.1 for an overview map of the study area.)

Burrard Inlet is a tidal waterway with peak water levels associated with low pressure storms and tidal fluctuations which usually coincide in the winter months (December to February). This area of the harbour is generally well sheltered from exposure to large waves, and is dominated by a combination of small wind-waves along with frequently occurring vessel wake waves. SLR is predicted in this location.

Figure 1.1 Study area along Waterfront Road at the Convention Centre and Canada Place

The area is complex and has multiple levels. The street level of Canada Place and the northern extents of Howe and Burrard Streets are built up upon elevated decking. This area is a busy public thoroughfare with significant tourist, commuter and local business and conference traffic. The upper level has access to the VCCW, Canada Place (Cruise Ship Terminal, Convention Centre East, Pan Pacific Hotel, Port of Vancouver offices, etc), Harbour Air and numerous other businesses within these buildings. The upper level also contains a publicly accessible seawall walkway and numerous public art installations.

Below this level, Waterfront Road runs roughly east-west at a low elevation. It is open to the east, and goes below ground on the west side of the study area where it eventually u-turns and rises to connect with the above grade West Cordova Street. Near to this u-turn is access to the seawall at Coal Harbour and to the seaplane terminal on the western side of the VCCW. At the east end of Waterfront Road, there is the SeaBus Terminal to the north and a railyard to the south. The SeaBus Terminal is operated by TransLink and provides a key transportation link between North Vancouver and downtown. The railyard is operated by Canadian Pacific Railway, while TransLink operates the SkyTrain and West Coast Express tracks along the southwestern side of the railyard.

Where Waterfront Road proceeds underground, to the south there are entrances to several underground parking structures, loading bays and utilities for servicing buildings and businesses including the Fairmont Waterfront and Pacific Rim hotels, a variety of small businesses and offices. To the north of Waterfront Road, there are utilities and loading docks for the VCCW and Canada Place. These facilities are heavily used for conferences, events, cruise ship loading, and host the Port of Vancouver offices. Several of these facilities are highlighted in Figure 1.2.

Figure 1.2 Image of the study area with key features highlighted (Google Earth, ESRI Basemap)

2 DATA COLLECTION AND REVIEW

2.1 LiDAR and Bathymetry Review

Aerial LiDAR of the study area was provided by the CoV. The LiDAR was flown by Eagle Mapping and collected overnight on August 27 and 28, 2018. The LiDAR point cloud was at a resolution of 20 points per metre. NHC received the data in LAS format and used the bare-earth classification for the DEM.

Bathymetric data of Burrard Inlet was collected in support of the 2014 CoV study. The data was from single and multibeam data from the Canadian Hydrographic Service (CHS), which was converted from chart datum to geodetic (chart datum is -3.1 m geodetic).

The current study requires topographic detail of Waterfront Road beneath Canada Place Way, which cannot be captured by aerial LiDAR. NHC coordinated the collection of terrestrial LiDAR to provide detail along Waterfront Road. The terrestrial LiDAR was collected by Underhill Geomatics Ltd. from April 10 to May 21, 2019, using a Leica RTC360 Scanner and a Trimble R10 Network Rover. The accuracy for terrestrial LiDAR changes with distance from the scanner, and can be expressed as follows:

- Angular accuracy 18”
- Range accuracy 1.0 mm + 10 ppm
- 3D point accuracy
  - 1.9 mm @ 10 m
  - 2.9 mm @ 20 m
  - 5.3 mm @ 40 m

A sample of the terrestrial LiDAR point cloud at the Shaw Tower parkade along Waterfront Road is shown in Figure 2.1. There was significant noise and artifacts in the supplied terrestrial LiDAR and consequently the project team was required to devote significant time and effort to cleaning this data for use in the building of the DEM.

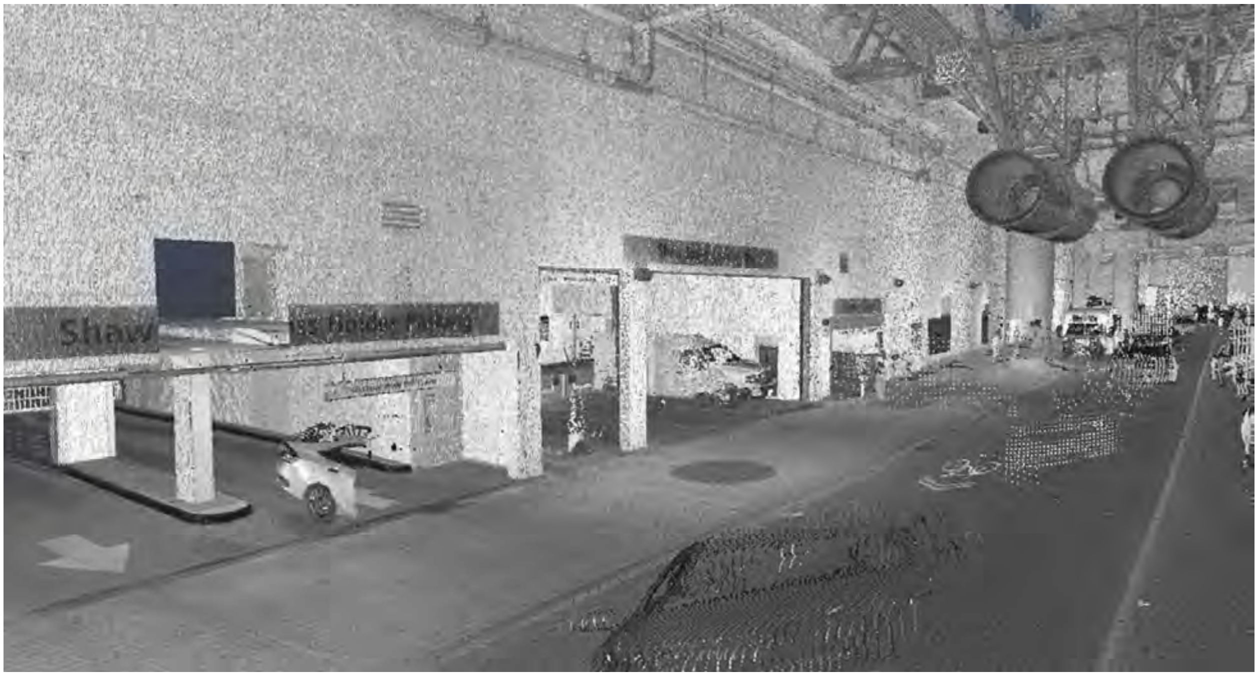

Figure 2.1 Sample of terrestrial LiDAR point cloud, looking west along Waterfront Road near the entrance to the Shaw Tower parkade

2.2 Field Surveys

Site inspections revealed several areas that required additional data that was either not included in the terrestrial LiDAR or in an area of sparse returns. Such areas include the sea walls, parking structures and a low trough-like structure near the eastern end of the area beneath Canada Place Way. The trough is approximately one metre wide and a half metre deeper than the surrounding parking area. This low area would allow any water that flows over the Waterfront Road crest to inundate the western edge of the railroad tracks to the south.

The aerial LiDAR did not adequately capture seawall elevations or areas beneath rooftops and overhangs. The DEM based on aerial LiDAR was modified based on elevations sampled from the terrestrial LiDAR point cloud and confirmed with field measurements relative to deck / road elevations.

The parkades were not picked up in the terrestrial LiDAR, but the road elevations at their entrances were. To determine the depth of these structures, two field visits were conducted and depths, relative to road elevations were collected using a laser range finder with vertical height capabilities. Elevations were checked against available record drawings. A final site inspection was conducted after the DEM was completed and initial model runs had been conducted. This inspection was intended to confirm assumptions that were made during the DEM development and clarify the layout of topographic features that lacked accurate representation in the data. Subsequent DEM revisions were made to improve the model.

3 HYDRAULIC MODELLING

3.1 DEM Development

The DEM for this project was developed from a combination of aerial LiDAR from the City of Vancouver (collected by Eagle mapping, August 2018), terrestrial LiDAR for the area under Canada Place Way (collected by Underhill, April to May 2019) and bathymetry extracted from the previous model created by NHC (based on CHS data). The two LiDAR datasets were compared in overlapping flat areas such as roads and parking lots and checked in random locations for consistency in elevation. Average observed differences were 2 to 3 cm with one surface not consistently higher than the other. The DEM was produced using the following Coordinate System: NAD1983 CSRS UTM Zone 10N; CGVD28 in order to keep the results consistent with the previous study and the commonly used CGVD28 vertical datum.

To reflect the high resolution of the LiDAR data sets, the DEM was generated at a 0.5 m cell size. The DEM covers the Vancouver harbour including English Bay, Burrard Inlet and Indian Arm as well as the area including the Central Waterfront District extending west to Vancouver Convention Centre West (VCCW) and south to Hastings Street.

The DEM was developed to support the hydraulic modelling effort. As a result, the DEM is not a true representation of the topography at all locations. Some important notes regarding the DEM creation are as follows:

- The boundary between the terrestrial LiDAR (representing underground areas) and aerial LiDAR (representing unobscured areas) results in abrupt increases in elevation within the DEM in some locations (Figure 3.1). These areas were confirmed to be outside of the limits of expected flooding.
- Where areas required modifications in elevations due to poor coverage of the terrestrial LiDAR or inaccessible areas, grids of fixed elevation were mosaicked into the DEM. The assumed elevations were based on information extrapolated from the LiDAR, from record drawings, or based on field observations, and were generally made to limit their influence on the model results. This adjustment is visible in locations including Canada Place and VCCW. Residual extrapolated model surface areas (visible as triangular artifacts) are visible in the DEM topography, however do not reduce the accuracy of the modelling.
- The lowest parking level of each parkade is represented in the DEM. Intermediate parking levels are not represented within the DEM.
- The coast-facing walls surrounding VCCW, and some concrete barriers are explicitly included within the DEM where they have an effect on the modelling.
- Buildings and walls were only included in the DEM in locations where they have a significant influence of flooding within the study area. This includes VCCW and certain parkade / loading bay walls.

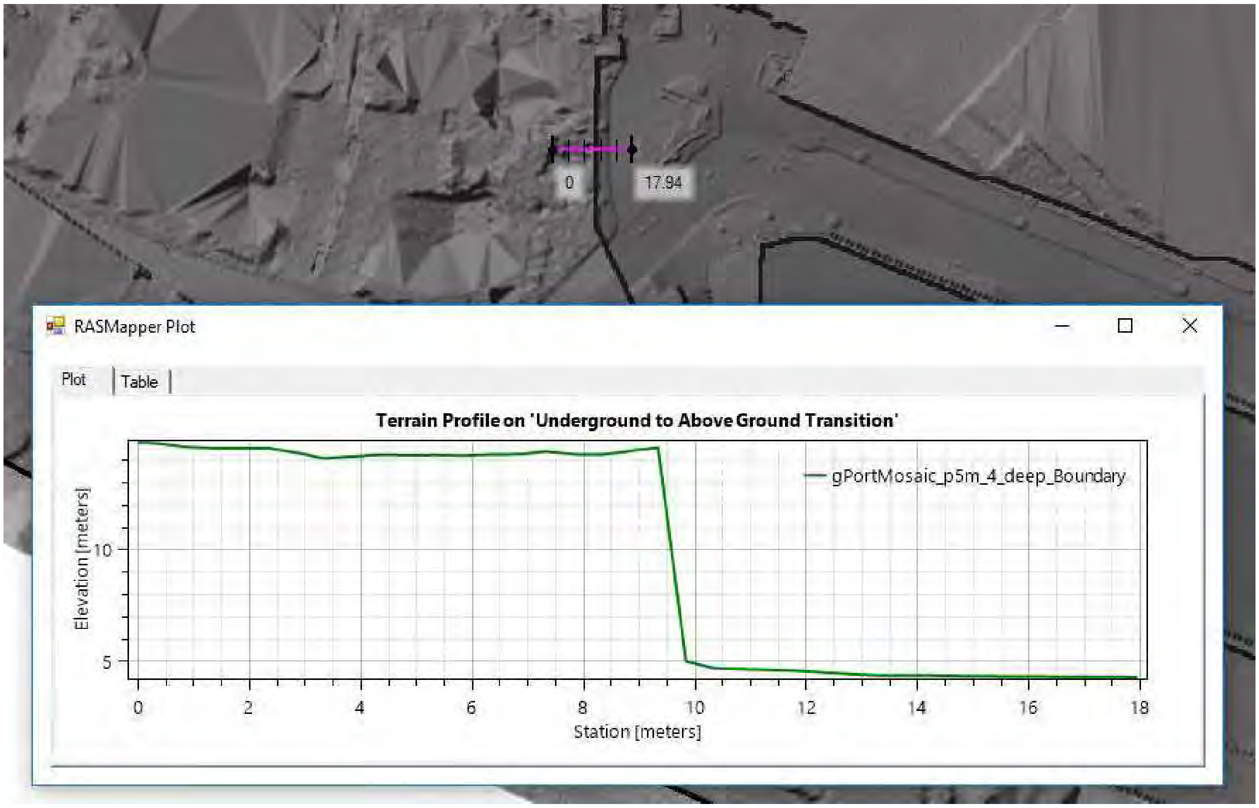

Figure 3.1 Terrain profile showing example of abrupt transition in DEM between above ground aerial LiDAR ground (left) and underground terrestrial LiDAR (right)

3.2 Modelling

3.2.1 Model Development

We developed a two-dimensional (2D) hydraulic model using RAS2D (v5.0.7). RAS2D was selected because of its ability to utilize variable cell sizes in its computational mesh, while retaining the resolution of the underlying topography contained in the DEM.

The model domain covers Burrard Inlet, from Point Atkinson to the northern extent of Indian Arm (Figure 3.2). The computational mesh is comprised of 100 m cell sizes, with refinements to 50 m between First Narrows and Second Narrows, 25 m along the shoreline between First Narrows and Second Narrows, and variable cell sizes down to 5 m within the study area (Figure 3.3). The DEM described in Section 3.1 was used to represent the bathymetric and topographic data within the model domain, with an underlying grid size of 0.5 m.

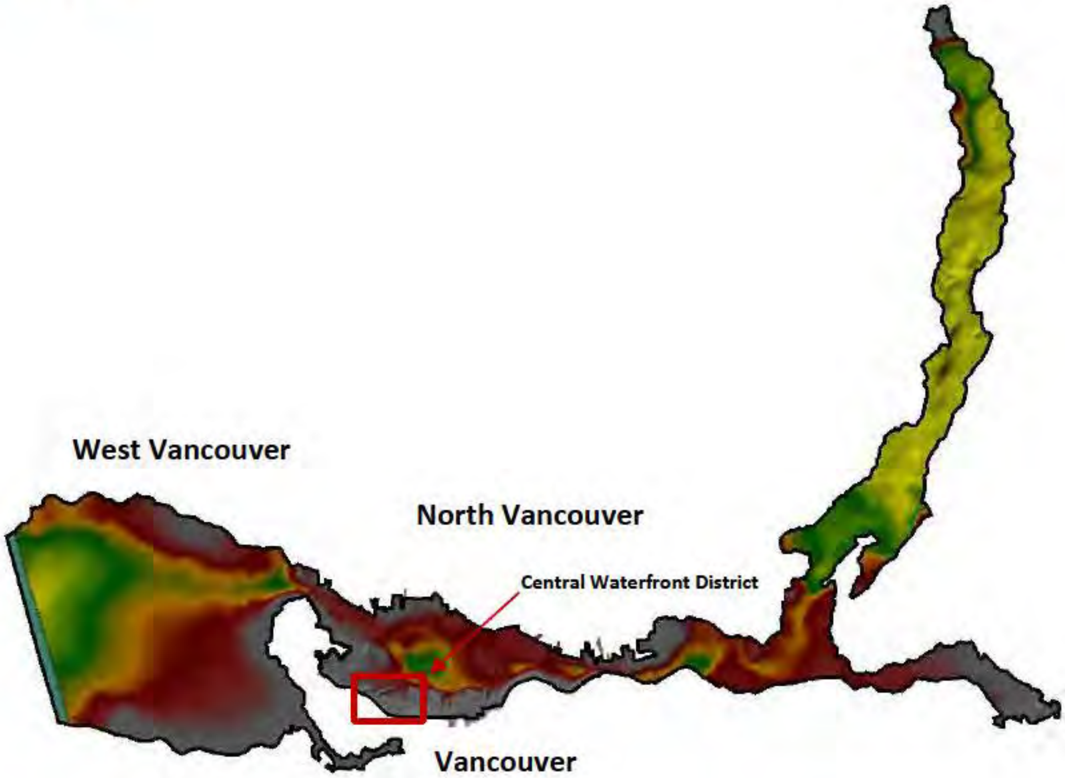

Figure 3.2 Model domain and underlying DEM

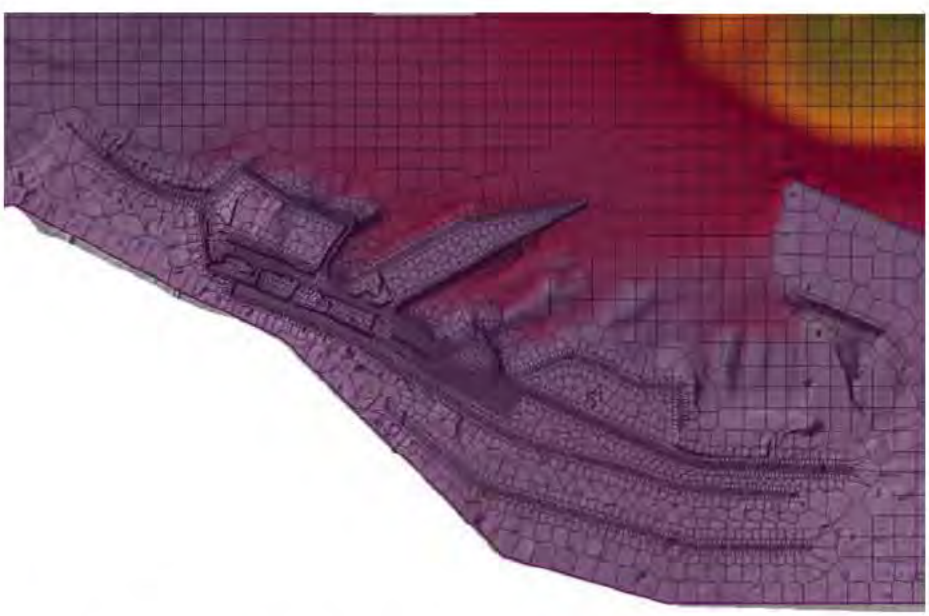

Figure 3.3 Computational mesh refinements within the study area

3.2.2 Model Scenarios

Four flood scenarios were modelled, reflecting various SLR projections and storm hazards. The scenarios are listed in Table 3.1, along with the peak offshore water level associated with each.

Scenarios 1 and 3 match the previous flood modelling done with SLR and storm surge scenarios aligned with the 2014 CoV study. Scenario 2 represents an interim planning scenario. Scenario 4 represents a more severe SLR scenario based on a recent Natural Resources Canada study (Han et al.,2016) which incorporates allowance for Antarctic ice sheet melting. It is expected that future scientific studies will provide updated estimates of global and regional SLR as well as more information about anticipated timelines (NHC, 2019).

Table 3.1 Modelled SLR and storm scenarios

Scenario	SLR (m)	Storm hazard return period (year)	Offshore Water Level (El. m)
Scenario 1	0.0	500	2.97
Scenario 2	0.5	50	3.23
Scenario 3	1.0	500	3.97
Scenario 4	1.6	500	4.57

The tidal component is based on the higher high water large tide (HHWLT) that occurred during the December 17, 2012 spring tide ('king tide') event, as was used in the 2014 CoV study. SLR projections were added to each point in the underlying time series for Scenarios 2, 3, and 4.

The storm hazard component was developed during the 2014 CoV study, based on a 50-year hindcast of water levels at the Point Atkinson tide gauge. The return periods represent the joint probability of the astronomical high tide coinciding with meteorological conditions that further raise the water level. Additional detail can be found in the CoV CFRA report (NHC, 2014).

The tidally varying water levels are used as boundary conditions to drive the overland flood model and are consistent with the CoV study (NHC, 2014). In each scenario, two full tidal cycles are applied to the model before the onset of the storm event (Figure 3.4). This allows the model to 'initialize' before the storm, and better represents the total flood volume that would enter into the study area over the tidal cycles. Importantly, it also highlights areas that may be subject to flooding during normal tide cycles under various SLR scenarios (without the influence of storms).

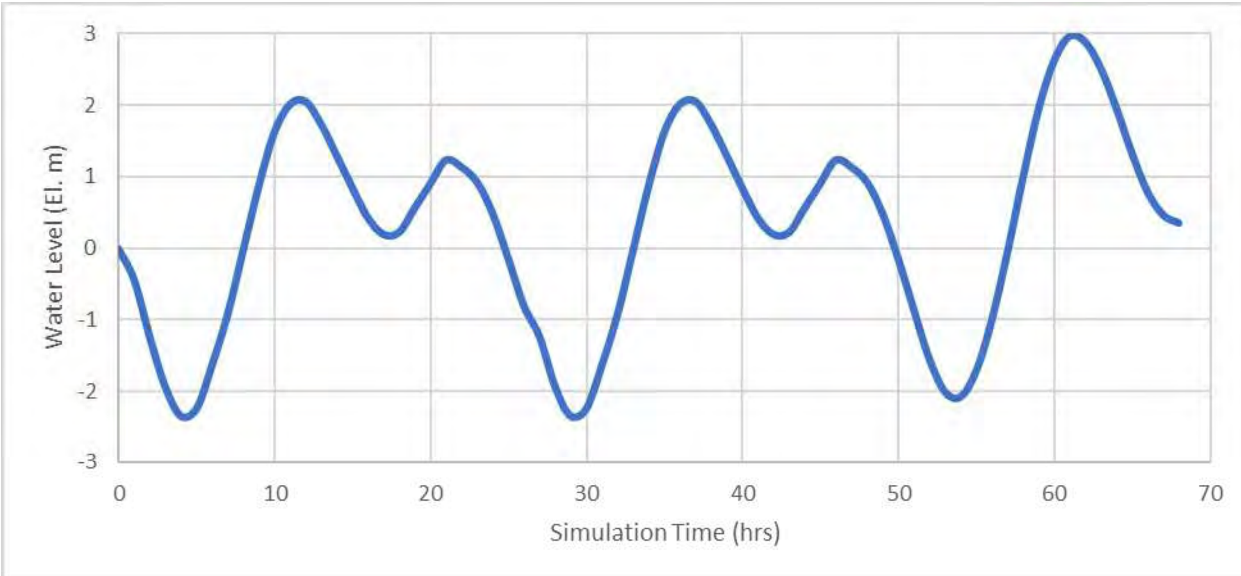

Figure 3.4 Sample tidal cycle used as forcing for overland model (Scenario 1 shown).

3.2.3 Model Validation

We ran a scenario using the December 17, 2012 spring tide event to validate the model results, focusing on the study area. Figure 3.5 compares the observed and modelled flood extents during the event, and shows reasonable agreement between the two. No validation data was available to verify the performance of the overland component of the model.

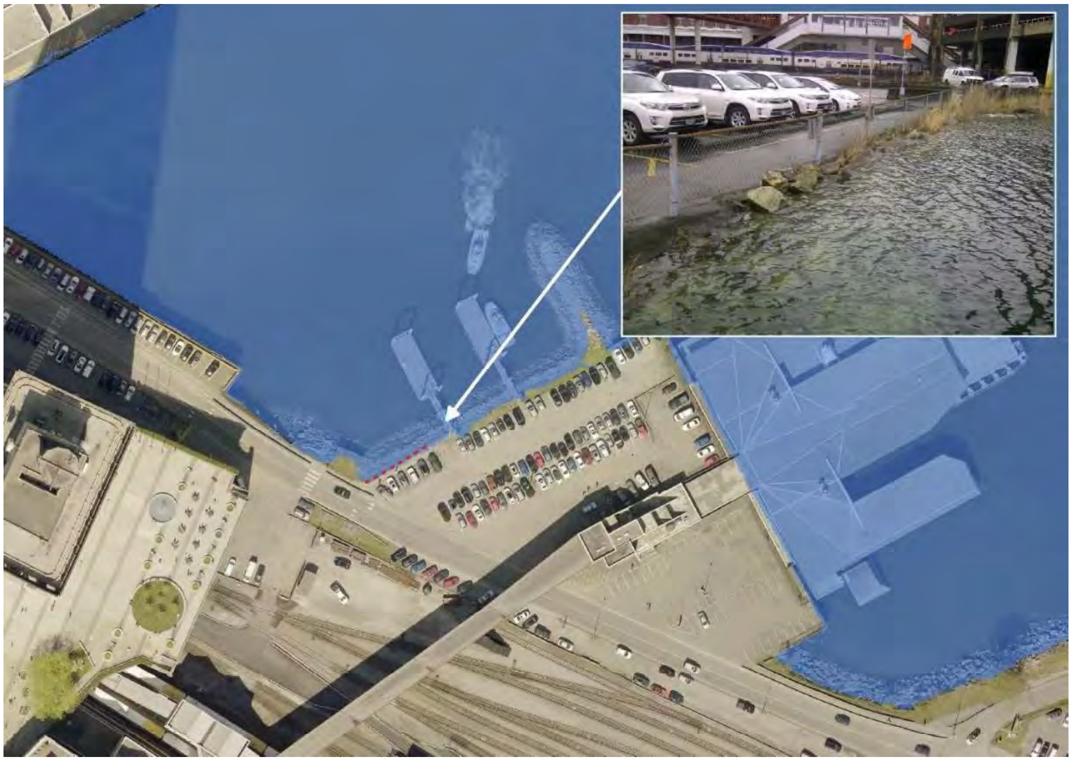

Figure 3.5 Comparison of observed (photo and red-dashed line) and modelled flood extents near SeaBus Terminal for December 17, 2012 (Note: the SeaBus Terminal and other floating structures were not included in the model)

3.2.4 Model Limitations

The accuracy of simulated water levels and other output data is limited by the following:

- The current model focuses on the section of Waterfront Road below Canada Place Way. The accuracy of the model output is limited by the accuracy of the DEM. The topographic detail of underground areas away from Waterfront Road are not fully resolved due to difficulty gaining access to these areas for surveys. These areas include:
  - The SkyTrain tunnel and section of rail line west of Waterfront Station
  - Additional parking areas south of the SkyTrain line
  - The access road and loading bays on the north and east sides of VCCW
- One critical location identified for flood ingress is through a low section of wall along the north side of VCCW (Figure 3.6). Numerous attempts were made to contact VCCW to provide wall elevations, but we did not receive the information. The model assumes an elevation of 3.1 m (geodetic) at the low point. The assumed elevation influences when flooding will overtop the wall.

Figure 3.6 View of north side of VCCW showing varying elevation of wall that is poorly resolved on LiDAR and survey information.

- The barrier walls surrounding the VCCW were included in the model and were assumed to provide flood protection. These structures may not have been designed to be watertight (Figure 3.7) or withstand hydraulic and debris impact loads during a flood event.

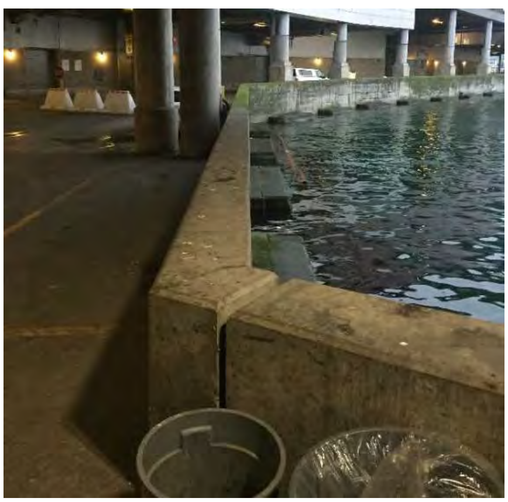

Figure 3.7 View of barrier wall at southeast corner of VCCW (Note that expansion joint is not sealed watertight).

- With the exception of VCCW and critical locations near the parkades and loading bays, walls and buildings were not included in the DEM or the model. The extents shown reflect the extents reached by unimpeded flow.
- The modelled flood levels are based on ground conditions at the time of the surveys, and supplemented by assumptions made during DEM development based on available information. Changes to ground elevations, land use or buildings from those included in the model will affect

flood levels. Similarly, obstructions caused by fences, walls, hedges, vehicles, pillars, boats, and debris that may be present during a flood are not represented in the model.

- The storm hazard return periods used in each scenario assume that future meteorological conditions that influence storm surge are similar to those experienced in the past, which may not be the case.
- Interaction between other water sources (i.e. precipitation, groundwater, or sewer surcharge) and complex interactions between subsurface drainage networks and structures (e.g. SkyTrain infrastructure, underground parking above the lowest parking levels, sump pumps, conduits, etc.) were not considered, and can affect localized flood levels.
- Drainage systems (storm pipes, catch basins, and pumping systems) were not included in the model. These systems may provide some flood relief during the recession of the flood, but would likely have limited effect on the flood peak. Drainage systems may provide additional pathways for back-flooding, circumventing other flood barriers if backflow prevention devices (e.g. flap gates) do not exist.
- The surface porosity and water storage capacity is not modelled. Some areas such as the railyard which is covered in crushed gravel, may store floodwater below the modelled elevation.

The model limitations and uncertainties should be considered when making decisions based on the model results.

nhc

4 WAVE EFFECT ASSESSMENT

When inundation occurs, waves will propagate from coastal waters, past sea barriers such as the seawall, and travel inland. Variation in topography and obstacles such as headlands, the seawall and buildings, result in spatial variability of the wave field. A nearshore wave model, Simulating Waves Nearshore (SWAN), of Burrard Inlet was developed to simulate the propagation of waves over the flooded area. SWAN incorporates physical processes such as wave propagation, wave generation by wind, white-capping, shoaling, wave breaking, bottom friction, sub-sea obstacles, wave setup and wave-wave interactions in its computations. SWAN Version 41.20A was used for the study.

Waves caused by sources other than wind, including boat traffic, tsunamis or landslides are not considered in the analysis.

4.1 Wave Model Set up

Two SWAN model grids are used for the analysis: a fine grid model of Central Waterfront District and vicinity was nested in a coarse grid model of the Burrard Inlet (**Figure 4.1**). The coarse grid measures about 30 km east-west, and 13 km north-south, with each grid cell measuring 50 m by 50 m. The fine grid measures about 4.7 km east-west, and 2.4 km north-south, with each grid cell measuring 10 m by 10 m. The model elevations are generated using the same DEM data used for the hydraulic model.

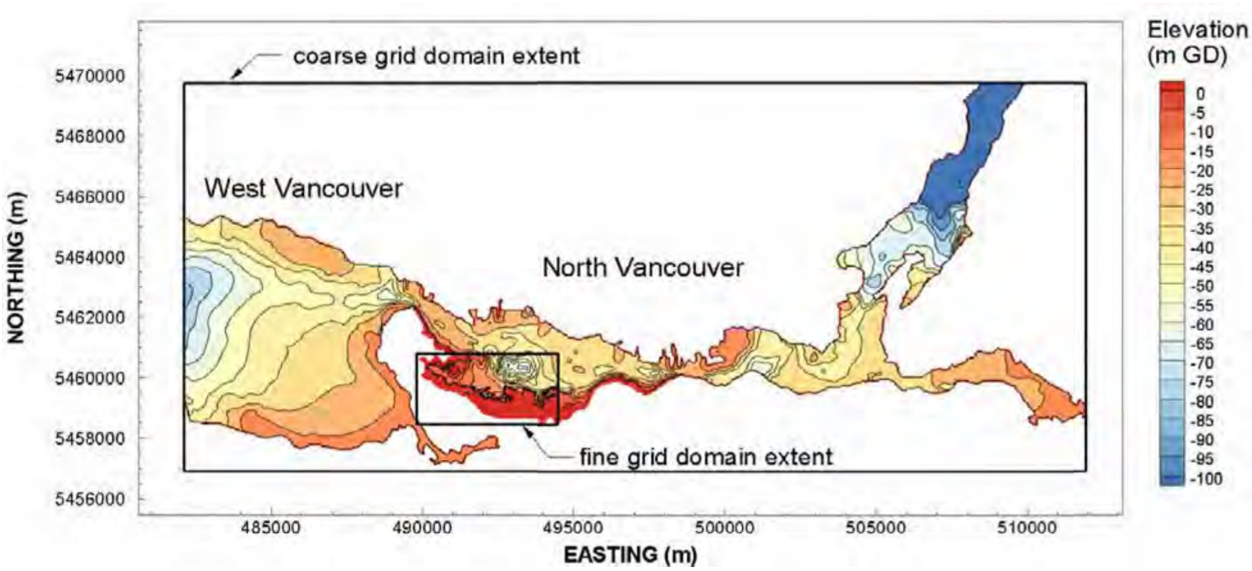

Figure 4.1 SWAN model grids

The wave model is initialized with the maximum water levels from the hydraulic model and forced with coastal water boundary conditions and local winds. In the previous NHC study for the CoV (NHC, 2014), the wave effect was evaluated based on typical wave conditions observed during high water events. The same storm conditions were adopted for this study. Wave conditions from the northwest and northeast were considered - the corresponding wind speeds are 10 and 12 m/s for northwesterly and northeasterly storms, respectively.

4.2 Wave Model Results

The SWAN model domain and vector fields showing the transformation of typical waves from the northwest and northeast under Scenario 4 conditions are shown in Figure 4.2 and Figure 4.3, respectively. Two percent exceedance wave height ($H_{2\%}$) distributions are shown with coloured shading, and wave direction and relative heights are shown with vectors. The vectors are shown for every 10 grid cells (i.e. 100 m apart).

In the previous NHC study for the CoV (NHC, 2014), a "wave effect boundary" was shown on the flood maps to denote the landward extent of waves of a sufficient height to be of concern as a hazard. This criteria was selected based on a FEMA study (Federal Emergency Management Agency (FEMA), 2014) which notes that "Recent post disaster assessments and wave tank research have shown that waves as small as 1.5 feet (0.45 metres) can cause significant structural damage." For planning purposes and to take a cautionary approach, the "wave effect boundary" is defined as smoothed representation of the 0.3 m $H_{2\%}$ contour in this study. These are represented as the purple line in Figure 4.2 and Figure 4.3. The maps in appendix A show the most landward extent of wave effects for all directions of waves for a given scenario of water depth.

Overall wave effects in the Central Waterfront District were found to be small. However, it is noted that on the VCCW there is a vertical wall (see Figure 3.6 and Figure 3.7) that will, with future SLR, become increasingly exposed to wave impacts. This study has not examined the capacity of infrastructure in the study area to withstand wave loading and to assess flooding it is assumed that there are no failures of the infrastructure (i.e. waves do not knock down the wall around the lower level of the VCCW.) It is also noted that this study utilizes the present day configuration of the Centerm container terminal, but that an expansion westward of this terminal is planned in the near future that, when completed, will likely serve to reduce the wave effects in the Central Waterfront District.

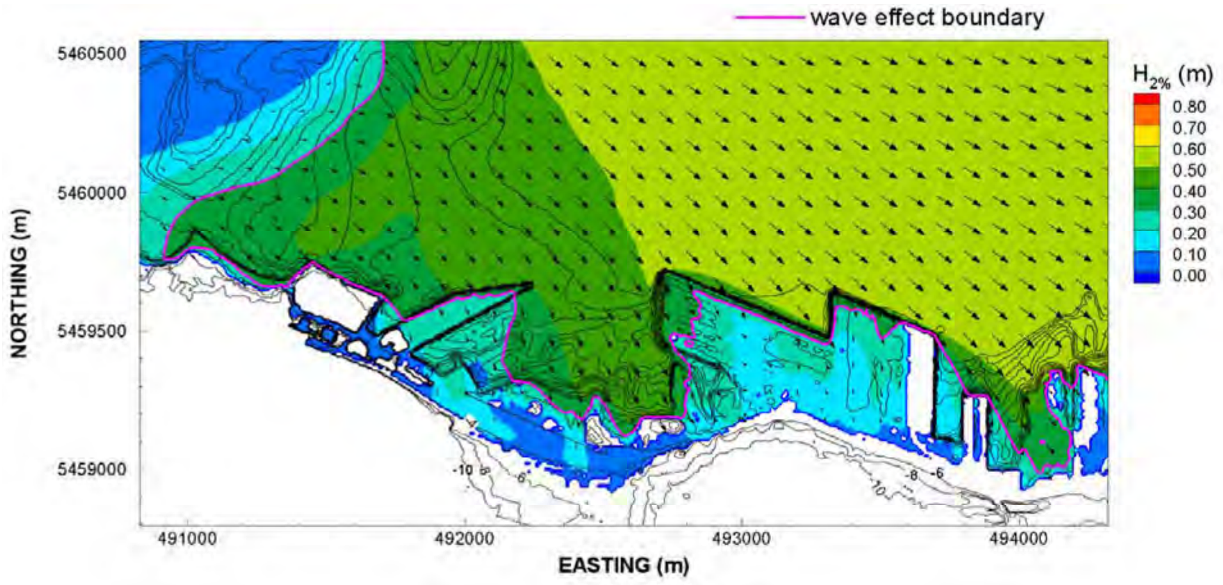

Figure 4.2 Wave height distribution – Scenario 4, Northwesterly Event

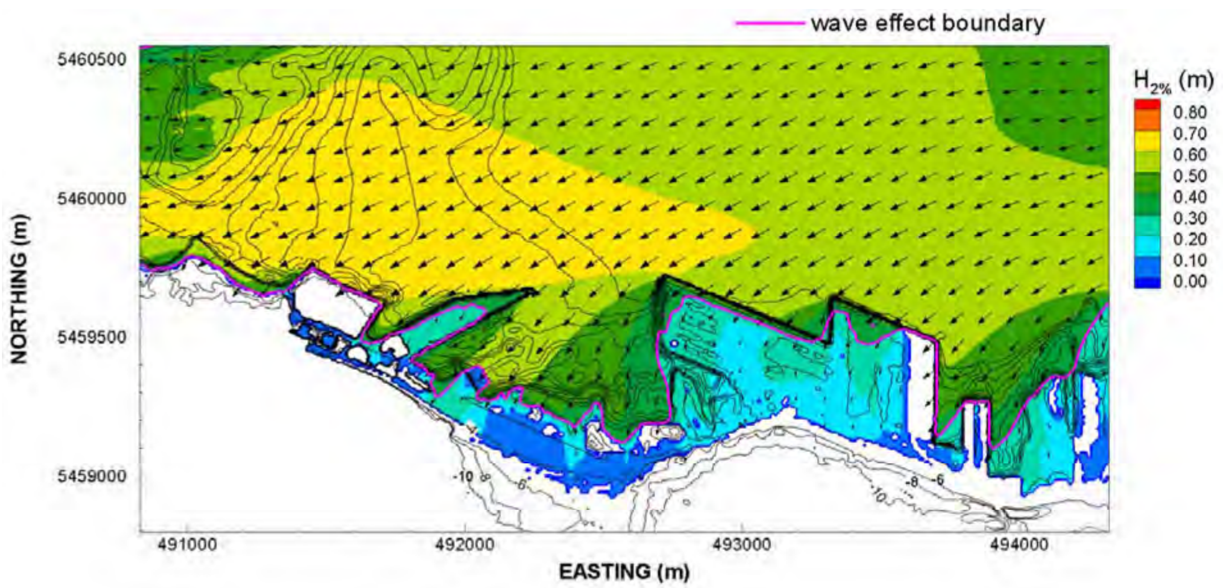

Figure 4.3 Wave height distribution – Scenario 4, Northeasterly Event

5 FLOOD HAZARD MAPPING

The flood mapping developed from the modelled scenarios is provided in Appendix A and has been developed following the Engineers and Geoscientists of BC (EGBC) floodplain mapping standards (APEGBC, 2017). For each scenario, two sets of maps are provided: a flood depth map and a flood extent map. The flood depth map does not include freeboard, but shows the maximum modelled extents, areas of high velocity and wave effects as described in Section 4. The flood extent map shows the maximum modelled extent, an additional 0.6 metres of freeboard, areas of high velocity, and wave effects as described in Section 4.

The depth classifications used in the mapping for this project differ from the previous CoV study mapping to better differentiate the shallow flood depths that tend to occur in this area, and reflect the level of detail of the hydraulic model.

On both sets of maps, areas exposed to wave and velocity hazards have been denoted. The wave affected areas were determined as described in Section 04, and are denoted by a dashed line along the perimeter of the flood extents in areas where waves are expected. Areas with potentially high velocity due to steep slopes or channelized flow (e.g. parkade entrances, access roads) are denoted on the maps, and were determined based on the model results and our understanding of the site.

The base mapping shown is a combination of aerial imagery and the hillshaded DEM developed for the study area. The DEM is shown where the important underground features are not evident from satellite imagery (Waterfront Road beneath Canada Place Way). Further detail around the DEM development and combination of surface and sub-surface elevations can be found in Section 3.1.

6 HAZARD ANALYSIS AND MITIGATION

6.1 Design Flood Assessment

While the four modelled scenarios have different peak water levels, flooding patterns are similar in each scenario. Ingress of flood waters into the study area tends to occur at three consistent low points (shown in Figure 6.1):

- Southwest corner of the SeaBus Terminal parking lot (approximate El. 2.9 m);
- The low point in the wall on the north side of VCCW (assumed El. 3.1 m); and
- The eastern edge of the Coal Harbour seawall at the seaplane walkway (approximate El. 3.4 m).

Flood durations are discussed for each scenario and location in Table 6.1.

Table 6.1 Approximate flood durations for various scenarios and locations

Scenario	Flooding onset to start of water receding (hours) [1]	Active flooding[2] at SeaBus Terminal (hours)	Active flooding at VCCW (hours)	Active flooding at seaplane walkway (hours)
Scenario 1	2.0	3	n/a	n/a
Scenario 2	2.75	4	2.0	0.5
Scenario 3	3.25	6	2.5	4.0
Scenario 4	4.0	7	6.5	6.0

1. Refers to the time between when flooding first begins to the time when the peak of the design event passes and water levels begin to drop.
2. "Active flooding" refers to the period of time from when flooding starts, to when recession of floodwaters causes hydraulic disconnection between the flooded area and the ocean. In reality, the area may be flooded for a longer time period, but as drainage and surface porosity are not modelled, this cannot be estimated.

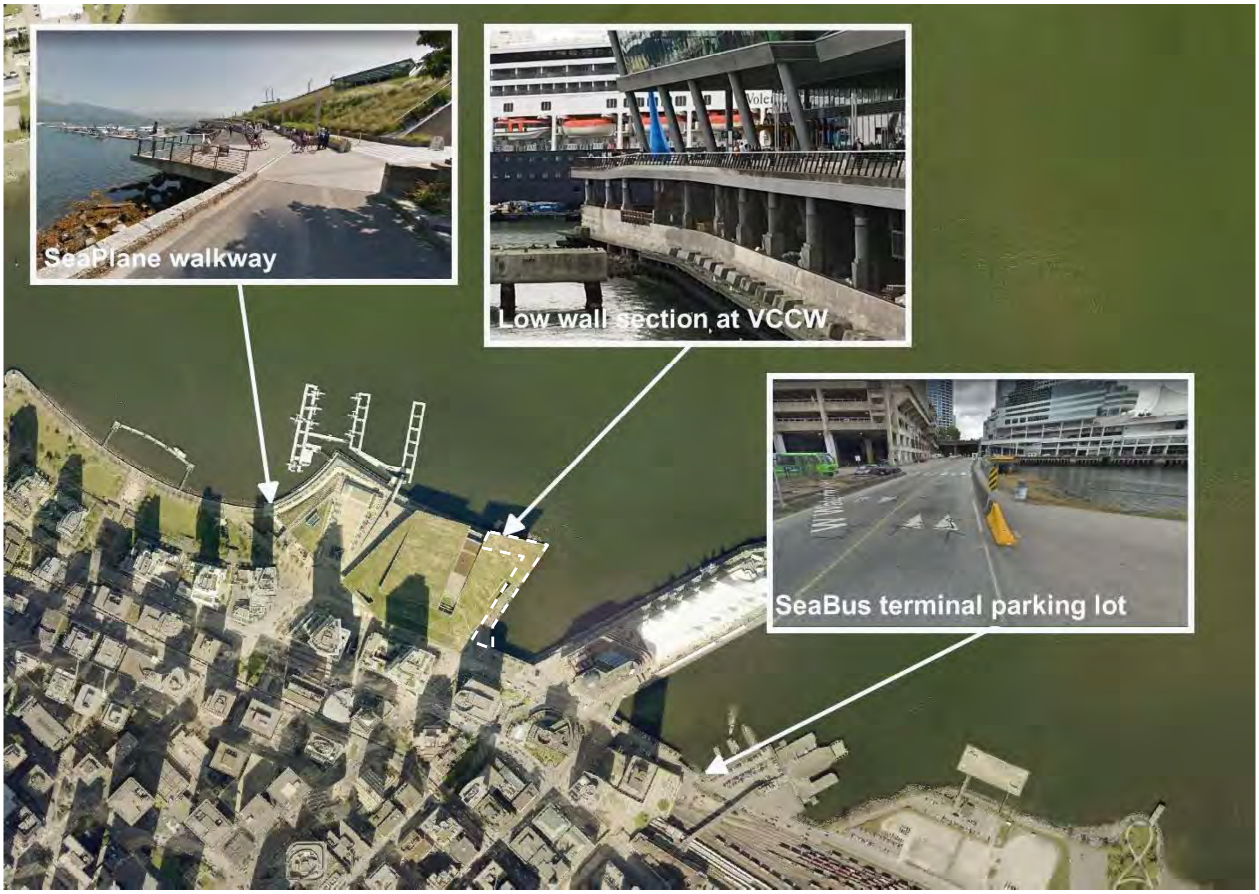

Figure 6.1 Initial flooding locations (dashed line shows underground access road linking flooding at VCCW low point with Waterfront Road)

In Scenario 1, flooding occurs during the design event, with water first inundating the area from the southwest corner of the SeaBus Terminal parking lot, overtopping Waterfront Road and extending into the railyard.

In Scenario 2, at the onset of the design event, the water first inundates the corner of the SeaBus Terminal parking lot, overtops Waterfront Road, and begins to flow through the railyard. As the water level continues to rise, the water then overtops the low point in the wall on the north side of VCCW and floods the access road around the building (Figure 6.2). The flooding from the VCCW wall and the SeaBus Terminal do not connect.

Figure 6.2 VCCW Access Road, looking N from Waterfront Road

In Scenario 3, the onset of the design event causes significant flooding of the SeaBus Terminal parking lot, over Waterfront Road, and into the railyard. The water then overtops the low point in the wall on the north side of VCCW, reaches Waterfront Road and begins to enter the parking structures. Water also overtops the eastern edge of the Coal Harbour seawall at the seaplane walkway, reaching Waterfront Road. In this scenario, flooding from all three ingress points connect, and result in considerable flooding of Waterfront Road and the parking structures.

In Scenario 4, the ingress of flood water follows the pattern of Scenario 3, occurring first at the SeaBus Terminal parking lot, then the low point in the VCCW wall, and then near the Coal Harbour seawall at the seaplane walkway. The water entering from the SeaBus Terminal and the VCCW wall connect to inundate the entire railyard, and merge with the water from the Coal Harbour seawall to result in substantial flooding along all of Waterfront Road, including the parking structures. As water levels continue to rise, they surpass the elevation of much of the shoreline infrastructure, including the walls around VCCW, and the 4K (dock) level of Canada Place. Flood extents reach as far south as Trounce Alley.

We note that in Scenarios 2, 3, and 4, the higher high water of the two tidal cycles leading up to the design storm event result in some flooding of the study area, increasing in extents and depth for each scenario. The flooding is limited to the SeaBus Terminal parking lot and western extent of the railyard for Scenarios 2 and 3, but extends to the VCCW access road, Waterfront Road, and the parkades in Scenario 4. This suggests that with certain SLR scenarios, flooding during 'normal' tidal cycles (i.e. not related to extreme storms) can occur. The potential disruption caused by these conditions is discussed in further detail in Section 6.3.

6.2 Design Flood Impact

6.2.1 Scenario 1

Scenario 1 is modelled with 0.0 m of SLR and a 500 year storm hazard return period. Scenario 1 aligns with a scenario modelled in the 2014 CoV study and represents a significant storm with present-day ocean levels.

In Scenario 1, the impact of the flooding is limited to the SeaBus Terminal parking lot and the western portion of the railyard (Figure 6.3), since Waterfront Road is only overtopped near the peak of the storm event. The western portion of the railyard is lower than the eastern portion, and closer to the limited inundation source. Flood depths in this area are less than 0.5 m. Velocities are not anticipated to be significant, however the area adjacent to the shorelines will be affected by waves which increase the hazard posed by the water depth. The flooding in the SeaBus area will impede deck access to the SeaBus Terminal by bicycles and cars. The non-floating part of the SeaBus Terminal including the elevators and escalators down from the over-track walkway will be impacted by the flooding. Functionality is anticipated to be interrupted during the storm event which is expected to have approximately 3 hours of active[1] flooding. Damage due to the 0.5 m depth of water on the exterior of the building is expected to be minor, especially if emergency floodproofing (i.e. sandbags) is implemented. Damage could include impact to electrical and mechanical systems that could disable elevators and escalators for a long period of time. If the floodwaters include debris carried from other locations around the harbour, damage could be more significant. The access to the two Port of Vancouver docks on the west side of the SeaBus Terminal is flooded.

[1] Active flooding refers to the period of time from when flooding starts, to when recession of floodwaters causes hydraulic disconnection between the flooded area and the ocean. In reality, the area may be flooded for a longer time period, but as drainage and surface porosity are not modelled, this cannot be estimated.

Figure 6.3 Photo looking NW from SeaBus elevated walkway

Flooding in Scenario 1 is also expected to impact the western portion of the railyard with flood depths less than 0.2 m. This minimal flooding may cause temporary interruption to railway operations, but is not expected to cause any damage. Velocities in this area will be minimal, and wave effects are not anticipated.

6.2.2 Scenario 2

Scenario 2 is modelled with 0.5 m of SLR and a 50 year storm hazard return period. This scenario is an interim planning scenario showing a shorter-term SLR scenario with a likely storm hazard.

In Scenario 2, the flooding on the SeaBus Terminal parking lot reaches up to 0.75 m. At this depth, the access would be interrupted as identified in Scenario 1 and velocities and waves would be a hazard to people in the area. More substantial damage may occur to the SeaBus Terminal due to the depths, velocities and possible debris. Repairs would likely need to be made before use resumes. The access to the two Port of Vancouver docks on the west side of the SeaBus Terminal is flooded. The active flooding at the SeaBus Terminal lasts approximately 4 hours.

Flooding in the railyard covers most of the tracks with depths between 0.1 m and 0.5 m. This is likely to interrupt track usage, as some electronic brakes on railcar wheels are below 0.5 m. Interruptions to track access would also be expected as flood depths between 0.1 m and 0.5 m can cause people to fall and are potentially dangerous (APEGBC, 2017; Cowichan Valley Regional District, n.d.). Although access to and use of the tracks would be interrupted, it is unlikely that significant damage would occur due to the low velocities anticipated. The railway tracks in the railyard should be inspected before resuming use to ensure no erosion occurred. Water also flows into the covered railway tracks below 200 Granville Street up to depths of approximately 0.1 m. Water here is anticipated to cause interruption but not damage. Inspection of tracks should be done before use resumes.

Water entering through the low point in the wall on the north side of VCCW floods the lower level the north and east sides. Depths in this area are less than 0.5 m, and would interrupt and pose a hazard to operations in this area including loading and unloading. The active flooding at VCCW lasts approximately 2 hours. The water is unlikely to cause significant structural damage, although may flood low-lying electrical infrastructure, and could flood below-grade loading facilities (e.g. elevators) and damage any items stored here for convention centre uses.

The water from the north of VCCW flows onto Waterfront Road both near VCCW and at the SeaBus Terminal, impacting access to Canada Place. Flow depths exceed 0.3 m in both locations which can cause a hazard to vehicle traffic as this depth can float many types of vehicles (Cowichan Valley Regional District, n.d.). During a Scenario 2 flood event, lower-level access to the 4K level of Canada Place[2] would be interrupted.

Some localized flooding occurs along the eastern edge of the Coal Harbour seawall at the seaplane walkway to depths of approximately 0.3 m for less than an hour.

6.2.3 Scenario 3

Scenario 3 is modelled with 1.0 m of SLR and a 500 year storm hazard return period. With this level of SLR, minor flooding under high tide conditions without significant storm surge may occur (see Section 6.3 for further discussion on this situation).

In Scenario 3, flooding at the SeaBus Terminal reaches depths between 1.0 m and 1.5 m. At this depth, the water and associated waves are very hazardous and expected to cause substantial damage to the terminal buildings which may take significant time to repair. Based on depth-damage curves used in the United States for commercial and institutional buildings, depths between 1.0 m and 1.5 m cause damage approximately equal to 50% of the building's value (FEMA, n.d.). Depending on resources available, this type of damage can take between one month and one year to fully repair. Service delivery would be interrupted to varying degrees during the repair period. The access to the two Port of Vancouver docks on the west side of the SeaBus Terminal is flooded. The active flooding at the SeaBus Terminal lasts approximately 6 hours.

The water in the railyard near the SeaBus Terminal reaches between 0.5 and 1.0 m. As the bottom of railcars are typically approximately 0.9 m off the ground, these flood depths have the potential to damage rail cargo and move railcars. Some of the buildings south of the railyard along Water Street also experience inundation in this scenario. Water flows into the covered railway tracks below 200 Granville Street up to depths of approximately 1.3 m. This depth of water could cause damage to railcar cargo and

[2] 4K is the name of the lower level of Canada Place (the level which connects with Waterfront Road) and refers to the dock elevation being 4000mm above mean sea level.

may cause erosion or other damage. As discussed in the limitations section, the topography near the SkyTrain tunnel entrance is not fully resolved in this model. It is anticipated that there may be connectivity between the underground rail passageway with 1.3 m of flooding and the SkyTrain tunnels leading to flooding of the SkyTrain tunnel in this scenario.

Water entering through the low point in the wall on the north side of VCCW and along the eastern edge of the Coal Harbour seawall floods all sides of the lower level of the VCCW building. For much of the lower level, the flooding is between 0.5 m and 1.2 m deep. The active flooding from VCCW lasts approximately 4.5 hours, and the flooding from the Coal Harbour seawall lasts approximately 4.0 hours. Along the lower level of the main convention centre building, flooding would disrupt loading and unloading operations in this area. Walking or operating a vehicle in this area would be hazardous, and the water and waves may cause damage to loading facilities, especially electrical components and inundate loading docks, however infrastructure on the lower level was not able to be confirmed for this project. The seaplane terminal and Harbour Air facilities are located along the lower level of the western portion of the convention centre. The glass walled exterior of the terminal would be exposed to approximately 0.5 m of flooding, which, with the impact of waves and potential debris, could cause flooding inside the building. Flooding inside the building would require significant repair with damage potentially equaling 25% of the value of the structure (FEMA, n.d.). Waterfront Road is impacted by flooding in multiple locations in this scenario. It is inundated with between 0.5 m and 1.0 m of water near VCCW. The water along Waterfront Road would flow into parking structures along this road and would accumulate. The flooding in the parkade, while not fully resolved in the model, is expected to reach significant depths, potentially fully flooding several floors and damaging contents including vehicles, and parkade infrastructure such as elevator, electrical and mechanical systems (Figure 6.4). Water entering the parkade structures also creates potentially high velocity areas where flows could increase the danger to people and vehicles in the area, and not allow vehicles to exit via the access ramps. Water that accumulates in parkades may not have any pathway to drain back out once the high tide recedes. While Waterfront Road is not flooded directly in front of Canada Place, there is flooding over the road near the SeaBus Terminal parking lot at depths of approximately 1.0 m. This flooding would eliminate access to and from Canada Place along the 4K level.

Figure 6.4 View of parkade on the south side of Waterfront Road between Canada Place and VCCW

The flooding along Waterfront Road near the SeaBus Terminal also impacts HVAC infrastructure at 200 Granville Street, with flooding up to 0.3 m adjacent to the concrete barrier exterior as shown in Figure 6.5.

Figure 6.5 HVAC system under 200 Granville Street along Waterfront Road

6.2.4 Scenario 4

Scenario 4 is modelled with 1.6 m of SLR and a 500 year storm hazard return period.

In Scenario 4, flooding in the entire Central Waterfront district is significant. At the SeaBus Terminal, depths range between 1.5 m and 2.0 m and active flooding at the SeaBus Terminal lasts approximately 7.0 hours. At this depth, the water and associated waves are very hazardous and expected to cause

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substantial damage to the terminal buildings which may take several days to repair. The access to the two Port of Vancouver docks on the west side of the SeaBus Terminal is flooded.

The water in the railyard near the SeaBus Terminal reaches between 1.0 m and 1.8 m. These flood depths have the potential to damage rail cargo and float or move railcars. Some of the buildings south of the railyard along Water Street also experience inundation in this scenario. Water flows into the covered railway tracks below 200 Granville Street up to depths of approximately 1.8 metres. This depth of water could cause damage to railcar cargo and may cause erosion or other damage. As discussed in the limitations section, the topography near the SkyTrain tunnel entrance is not fully resolved in this model. The elevated SkyTrain track has flooding at depths of approximately 0.3 metres at its northeastern end. As it is also anticipated that there may be connectivity between the underground railway and the tunnels, the SkyTrain is likely flooded in this scenario. Water entering through the low point in the wall on the north side of VCCW and along the eastern edge of the Coal Harbour seawall floods all sides of the lower level of the VCCW building. The active flooding from VCCW lasts approximately 6.5 hours, and the flooding from the Coal Harbour seawall lasts approximately 6 hours. For much of the lower level, the flooding is between 1.0 m and 2.0 m deep. Along the lower level of the main convention centre building, flooding would disrupt loading and unloading operations in this area. Walking or operating a vehicle in this area would be hazardous, and the water and waves may cause damage to loading facilities, especially electrical components and inundate loading docks, however infrastructure on the lower level was not able to be confirmed for this project. The seaplane terminal and Harbour Air facilities are located along the lower level of the western portion of the convention centre. The glass walled exterior of the terminal would be exposed to approximately 1.5 m of flooding, which, with the impact of waves and potential debris, would cause flooding inside the building and likely require significant repair.

Waterfront Road is impacted by flooding in multiple locations in this scenario. It is inundated with around 1.4 m of water near VCCW. The water along Waterfront Road would flow into parking structures along this road and would accumulate. The flooding in the parkade, while not fully resolved in the model, is expected to reach significant depths, potentially fully flooding several floors and damaging contents including personal vehicles, and parkade infrastructure such as elevator, electrical and mechanical systems. Water entering the parkade structures also creates potentially high velocity areas where flows could increase the danger to people and vehicles in the area, and not allow vehicles to exit via the access ramps. Waterfront Road directly in front of Canada Place is flooded to depths of approximately 0.5 m, and flooding over the road near the SeaBus is approximately 1.5 m deep. This flooding would eliminate access to and from Canada Place along the 4K level. The flooding along Waterfront Road near the SeaBus Terminal also impacts HVAC infrastructure at 200 Granville Street, with flooding up to 1.4 m adjacent to the concrete barrier exterior as shown in Figure 6.5.

The 4K level of Canada Place is also flooded with approximately 0.5 m of water. With this depth and potential wave effect, the 4K level would be hazardous to people and vehicle travel. Infrastructure on the 4K level could be damaged including: the shore power entrance located near Waterfront Road; optical fibre cables which run from seabed to ceiling along the south side of the building; electrical and Telus service through an underground duct along waterfront road; the water supply service room adjacent to Waterfront Road; the West Gate electric room; the electrical, mechanical, pump, generator, backup generator and meter rooms along the east side of Canada Place; the Pacific Cruise Lines (PCL) main switchgear room; the Holland America Line (HAL) main switchgear room; the sanitary sewer which connects from ceiling to sanitary main; various utility boxes; various shore power connections; and mobile gangways used for passenger loading onto or off cruise ships. The infrastructure on the outer aprons would be directly exposed to water and waves and would likely have significant water damage. Berthing operations would not be possible when the deck is flooded. The infrastructure on the interior of the building would be affected by floodwater which reaches the interior of the building. Some water is likely to reach the interior through loading docks and unsealed pathways.

6.2.5 Scenario Comparison

Table 6.2 compares the approximate flooding depths at key locations and infrastructure for each of the scenarios.

Table 6.2 Approximate flooding depths at key locations and infrastructure for each scenario. Impacts are coloured as follows: green – no impact; yellow – interruption; orange – some damage; red – significant damage.

Key Location or Infrastructure	Flooding in Given Scenario			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
SeaBus Terminal	0.5 m	0.75 m	1 - 1.5 m	1.5 - 2.0 m
Railyard near SeaBus Terminal	Some flooding <0.2 m	0.1 - 0.5 m	0.5 - 1.0 m	1.75 - 2.0
Rail tracks below 200 Granville Street		0.1 m	1.3 m	1.8 m
SkyTrain tunnels		Potentially flooded	Likely flooded	Flooded
Low point on north wall of VCCW		Flooded	Flooded	Flooded
Eastern edge of Coal Harbour SeaWall		Some flooding, 0.3 m	Flooded	Flooded
Lower level of VCCW, exterior		0.5 m	0.5 - 1.2 m	1.0 - 2.0 m
Lower level of VCCW, interior		Potentially flooded	Likely flooded	Flooded
Waterfront Road near VCCW		0.3 m	0.5 – 1.0 m	1.4 m
Parkades off of VCCW			Flooded	Flooded
Waterfront Road in front of Canada Place				0.5 m
Waterfront Road near SeaBus		0.3 m	1.0 m	1.5 m
4K level of Canada Place				0.5 m
HVAC infrastructure at 200 Granville Street			0.3 m	1.4 m

6.3 "Blue Sky" Flood Assessment

As noted in Section 6.1, the SLR scenarios considered in this study result in some flooding within the study area during high tides alone in the absence of storm surge. Ingress occurs during the highest HHWLT events, but not during all high tides.

The three critical ingress points identified in the study area are the SeaBus Terminal parking lot, the low point in the VCCW wall, and the eastern edge of the Coal Harbour seawall. The critical elevations at these locations are El. 2.9 m, El. 3.1 m, and El. 3.4 m, respectively. Flooding in these locations results in disruptions to Waterfront Road, access roads, and loading bays in the study area.

To better understand how operations may be interrupted by SLR, we evaluated the proportion of time that critical elevations would be exceeded under current SLR, and with a SLR of 0.5 m, 1.0 m, and 1.6 m. Our assessment is based on a review of historical observed water levels in ten minute increments at the Point Atkinson tide gauge from 1999 to 2017.

The results represent the percent of time that disruption of operations due to flooding may be experienced, and are given in Table 6.3 to Table 6.5. The results account for high tides and storm surge, but reflect levels that have been historically observed (not necessarily extreme storm hazards). We considered disruptions to be likely when water levels come within 0.3 m of the critical elevations at each of the three critical locations. This value takes into account the potential for wave splash at each location. For each of the critical locations, the disruption drastically increases above 1.0 m SLR.

Table 6.3 Percentage of time that water levels are within 0.3 m of the level that may disrupt Waterfront Road near the SeaBus Terminal parking lot

SLR	Monthly (%)												Total Year
(m)	J	F	M	A	M	J	J	A	S	O	N	D	(%)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
0.5	0.5	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	**0.1**
1.0	7.6	3.5	2.3	1.2	2.4	3.2	2.5	1.5	0.6	1.8	6.3	9.2	**3.5**
1.6	29.2	23.0	22.2	21.4	22.6	24.8	25.3	21.3	17.9	21.7	27.0	30.3	**23.9**

Table 6.4 Percentage of time that water levels are within 0.3 m of the level that may overtop the low point in the VCCW north wall

SLR	Monthly (%)												Total Year
(m)	J	F	M	A	M	J	J	A	S	O	N	D	(%)
0.0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0**
0.5	0.5	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	**0.1**
1.0	3.3	1.1	0.8	0.1	0.2	0.5	0.3	0.1	0.0	0.3	2.4	4.2	**1.1**
1.6	21.3	14.8	13.3	12.9	15.0	17.1	16.4	12.2	8.7	13.1	19.7	22.9	**15.6**

Table 6.5 Percentage of time that water levels are within 0.3 m of the level that overtops the eastern edge of the Coal Harbour seawall near the Seaplane walkway

SLR	Monthly												Total Year
(m)	J	F	M	A	M	J	J	A	S	O	N	D	(%)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1.0	0.5	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	**0.1**
1.6	10.4	5.5	4.1	2.9	4.7	6.2	5.1	2.9	1.4	3.6	9.2	12.3	**5.7**

6.4 Mitigation Assessment

As sea level rises, the flooding hazard from both high tides and storm surge are expected to have significant impacts to the infrastructure and function in the Central Waterfront District area. Mitigations suggested for this area are primarily defensive, structural works with some adaptive measures. As the area and its assets are centered around access to water, and the surrounding area is very developed, retreat or relocation are not likely feasible, and so are not suggested as mitigation options.

Mitigation options are suggested in two forms: as primary mitigation works which would be independent projects, and opportunistic mitigation options that should be considered as other updates are made or in association with other planned infrastructure projects. A time-frame to complete the works is also identified as short-term (5-15 years), medium-term (15-30 years), and long-term (30-50 years).

Primary mitigation works:

- Address the low ingress point at the southwest corner of the SeaBus Terminal parking lot and Waterfront Road (short-term).
- Confirm the capability of wall around VCCW to withstand hydraulic loading, and its watertightness (short-term).
- Address the low point in wall on north side of VCCW (medium-term), along with necessary structural upgrades for hydraulic loading. Consider design of a re-curved crest on the wall to reduce the potential for wave splash overtopping.
- Address the low point at the eastern extent of the Coal Harbour seawall where it joins the seaplane walkway (medium-term).
- Develop a long-term strategy for addressing the significant potential inundation from SLR. A long-term strategy could include a comprehensive asset protection plan including developing an understanding of flood risk tolerance, further defining acceptable nuisance flooding, mitigation thresholds and preferred mitigation strategies. With 1.6 m of SLR or more, the usage of the area (as presently configured) is severely compromised.

Other mitigation works (opportunistic):

- Seal ingress points into lower floors of buildings, parkades, SkyTrain and loading bays through passive flood barriers, waterproofing, pumping, etc.
- Identify critical infrastructure located at lower levels and relocate and / or floodproof.
- Modify storage procedures for potential environmental contaminants / operational equipment to reduce likelihood of contamination or damage during flood.
- Ensure disaster response operations can function during a flood (personnel access, power and communications).
- Improve drainage systems (catch basins, storm pipes) to allow efficient drainage following recession of a large tide-storm combination and ensure flap gates and backflow valves are installed and maintained.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary of Findings

Through site visits and LiDAR collection and refinement, an understanding of elevations in the Central Waterfront District area was established, and a DEM showing ground elevation was developed. Modelling of four different SLR and storm surge scenarios with this DEM showed predicted flooding patterns in the district. Flood levels, while increased by storm surge events, seem to be most strongly affected by SLR.

The SeaBus Terminal is the first area to flood and experiences the deepest flooding as it has almost no protection and a low elevation at the shoreline. The railyard behind the SeaBus is also affected by fairly significant flooding, due a low point in Waterfront Road near the SeaBus Terminal parking lot.

Flooding of the lower level at VCCW also occurs at various depths depending on the scenario, with ingress through a low point in the wall along the north side of VCCW and at higher water levels via the eastern edge of the Coal Harbour seawall. This flooding would affect the seaplane terminal facilities as well as loading and infrastructure on this level.

Waterfront Road is flooded in most scenarios, and access to lower level of Canada Place is impacted. Flooding along Waterfront Road leads to flooding and anticipated high velocity hazards associated with the parkades along the road.

Canada Place experiences relatively limited flooding when compared to other buildings in the central waterfront area. It is only flooded in Scenario 4, and flood depths are less than 1.0 m. Flood depths are enough to damage infrastructure on the 4K level, especially electrical and mechanical equipment, and may impact the ability of the VFPA offices to function effectively during a major flood event. Further, this study has not examined the potential failure modes of the infrastructure on the 4K level of Canada Place from direct exposure to wave impacts. That said, the timeline for Scenario 4 may correspond with the expected service life of the existing infrastructure and a rebuild or upgrade might occur at or before such a scenario occurs.

As the area already has features that limit flooding, mitigation recommendations are focused on verifying their capability to withstand flooding and increasing the heights of existing defences, especially at low points. Over time, floodproofing to increase resiliency can also be considered.

7.2 Future Study

The project and associated limitations of analysis identified several items which need further study. The ability of the various seawalls and barriers analyzed in the project to remain watertight and withstand hydraulic and debris impact forces should be confirmed through additional analysis. The most critical location for this is around VCCW, where the walls provide considerable protection of Waterfront Road and the VCCW access road / loading bays until the elevation of the lowest point in the wall is exceeded. The elevation of the lowest point in the wall also must be confirmed. If further analysis finds that the elevation of the wall is considerably lower, the walls are not watertight, or are not capable of withstanding the anticipated forces, then the model results should be re-examined.

The hydraulic modelling effort focuses on overland flooding, and the potential effects of water depths inside buildings is not analyzed. If this is of interest, future projects could focus on refining the estimates and potential impacts of flood depths within building interiors and also to include storm drainage.

The impacts of flooding on the SkyTrain tunnels are estimated but not confirmed due to insufficient topographic data west of Waterfront Station. There is the potential for significant disruption to the SkyTrain system and West Coast Express in the event of the flood. To better understand these impacts, additional data on rail line elevations should be collected and the model should be refined to confirm critical elevations and hydraulic connections.

The impacts of other water sources are not considered, including precipitation, groundwater, and surcharge of storm or sanitary systems. These water sources could be considered through additional analysis and may contribute to higher water levels.

As mitigation options are considered and implemented, modelling could be updated with intended elevations to assess the effectiveness of the proposed solutions on mitigating flooding in the area.

8 CLOSURE

It has been our pleasure to work with the Port of Vancouver on this interested project. Please feel free to contact Grant Lamont via email at GLamont@nhcweb.com if you have any questions about this report.

9 REFERENCES

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APPENDIX A

Depth and Flood Extent Maps

26 August 2019

Burrard Inlet Flood Depths Not Including Freeboard

1. Flood water levels were developed for four coastal flood scenarios using information described in NHC (2019).
   The Scenario 1 map delineates the potential for coastal flooding for present shoreline conditions caused by a current 500-year return period ocean event. A 500-year return period ocean event means that there is a 1-in-500 chance that the flood level mapped could be equalled or exceeded in any one year.
   The Scenario 2 map delineates the potential for coastal flooding under future shoreline conditions assuming at 0.5 m sea level rise (SLR) and a current 50-year return period ocean event. A 50-year return period ocean event means that there is a 1-in-50 chance that the flood level mapped could be equalled or exceeded in any one year.
   The Scenario 3 map delineates the potential for coastal flooding under future shoreline conditions assuming at 1.0 m sea level rise (SLR) and a current 500-year return period ocean event. A 500-year return period ocean event means that there is a 1-in-500 chance that the flood level mapped could be equalled or exceeded in any one year.
   The Scenario 4 map delineates the potential for coastal flooding under future shoreline conditions assuming at 1.6 m sea level rise (SLR) and a current 500-year return period ocean event. A 500-year return period ocean event means that there is a 1-in-500 chance that the flood level mapped could be equalled or exceeded in any one year.
2. The adopted value for SLR is based on guidelines from Ausenco-Sandwell (2011) for scenarios prescribed by VFPA for this study.
3. The flood levels are based on water surface profiles simulated using a two-dimensional hydrodynamic model developed by NHC (NHC, 2019). Refer to the report for details and limitations of the model development.
4. The Digital Elevation Model (DEM) was developed based on Aerial LiDAR data surveyed for the City of Vancouver by Eagle Mapping Ltd. in 2018, Terrestrial LiDAR surveyed for this project by Underhill Geomatics Ltd. in 2019, and CHS bathymetric data. The DEM surface was edited to combine these three sources to support the modelling effort. The DEM surface was also modified to include (1) consistent sea wall elevations, (2) addition of the access road around the Vancouver Convention Centre West, (3) generalized elevations in areas that the terrestrial LiDAR did not reach (such as the railway tunnel), and (4) parkade lowest level elevations (determined though field measurements relative to road elevation and record drawings).
5. The modelled flood levels are based on ground conditions at the time of the surveys, and supplemented by assumptions made during DEM development based on available information. Changes to ground elevations, land use or buildings from those included in the model will affect flood levels. Similarly, obstructions caused by fences, walls, hedges, vehicles, pillars, boats, and debris that may be present during a flood are not represented in the model.
6. The accuracy of simulated flood levels is limited by the reliability of the water level data used for calibrating the model. Limited observational data was available, and only for one event with a lower peak water level than the future scenarios.
7. The accuracy of the location of a floodplain boundary is limited by the accuracy of the DEM, model boundary conditions and model parameters.
8. The wave analysis considered waves from both northwesterly and northeasterly wind events. The wave effect boundary shows the most landward extent of wave effects. The boundary is a smoothed representation of the combined (worse case) results for all directions of waves for a given flood scenario.
9. Interaction between other water sources (i.e. precipitation, groundwater, or sewer surcharge) and complex interactions between subsurface drainage networks and structures (e.g. SkyTrain infrastructure, underground parking above the lowest parking levels, sump pumps, conduits, etc.) were not considered, and can affect localized flood levels. A Qualified Professional must be consulted for site-specific engineering analysis.
10. Industry best practices were followed to generate the flood depth maps. However, actual flood depths and extents may vary from those shown and Northwest Hydraulic Consultants Ltd. (NHC) does not assume any liability for such variations.

Burrard Inlet Extents Including Freeboard

1. Inundation extents were developed for four coastal flood scenarios based on information described in NHC (2019).
   The Scenario 1 map delineates the potential for coastal flooding for present shoreline conditions caused by a current 500-year return period ocean event. A 500-year return period ocean event means that there is a 1-in-500 chance that the flood level mapped could be equalled or exceeded in any one year.
   The Scenario 2 map delineates the potential for coastal flooding under future conditions assuming a 0.5 m sea level rise (SLR) and a current 50-year return period ocean event. A 50-year return period ocean event means that there is a 1-in-50 chance that the flood level mapped could be equalled or exceeded in any one year.
   The Scenario 3 map delineates the potential for coastal flooding under future conditions assuming a 1.0 m sea level rise (SLR) and a current 500-year return period ocean event. A 500-year return period ocean event means that there is a 1-in-500 chance that the flood level mapped could be equalled or exceeded in any one year.
   The Scenario 4 map delineates the potential for coastal flooding under future conditions assuming a 1.6 m sea level rise (SLR) and a current 500-year return period ocean event. A 500-year return period ocean event means that there is a 1-in-500 chance that the flood level mapped could be equalled or exceeded in any one year.
2. The adopted value for SLR is based on guidelines from Ausenco-Sandwell (2011) for scenarios prescribed by VFPA for this study.
3. A freeboard allowance (safety factor) of 0.6 m is included in the flood levels shown to account for various sources of uncertainty in the model inputs and parameters.
4. The flood levels are based on water surface profiles simulated using a two-dimensional hydrodynamic model developed by NHC (NHC, 2018). Refer to the report for details and limitations of the model development.
5. The Digital Elevation Model (DEM) was developed based on Aerial LiDAR data surveyed for the City of Vancouver by Eagle Mapping Ltd. in 2018, Terrestrial LiDAR surveyed for this project by Underhill Geomatics Ltd. in 2019, and CHS bathymetric data. The DEM surface was edited to combine these three sources to support the modelling effort. The DEM surface was also modified to include (1) consistent sea wall elevations, (2) addition of the access road around the Vancouver Convention Centre West, (3) generalized elevations in areas that the terrestrial LiDAR did not reach (such as the railway tunnel), and (4) parkade lowest level elevations (determined though field measurements relative to road elevation and record drawings).
6. The modelled flood levels are based on ground conditions at the time of the surveys, and supplemented by assumptions made during DEM development based on available information. Changes to ground elevations, land use or buildings from those included in the model will affect flood levels. Similarly, obstructions caused by fences, walls, hedges, vehicles, pillars, boats, and debris that may be present during a flood are not represented in the model.
7. The accuracy of simulated flood levels is limited by the reliability of the water level data used for calibrating the model. Limited observational data was available, and only for one event with a lower peak water level than the future scenarios.
8. The accuracy of the location of a floodplain boundary is limited by the accuracy of the DEM, model boundary conditions and model parameters.
9. The wave analysis considered waves from both northwesterly and northeasterly wind events. The wave effect boundary shows the most landward extent of wave effects. The boundary is a smoothed representation of the combined (worse case) results for all directions of waves for a given flood scenario.
10. Interaction between other water sources (i.e. precipitation, groundwater, or sewer surcharge) and complex interactions between subsurface drainage networks and structures (e.g. SkyTrain infrastructure, underground parking above the lowest parking levels, sump pumps, conduits, etc.) were not considered, and can affect localized flood levels. A Qualified Professional must be consulted for site-specific engineering analysis.
11. Industry best practices were followed to generate the flood extent maps. However, actual flood levels and extents may vary from those shown and Northwest Hydraulic Consultants Ltd. (NHC) does not assume any liability for such variations.

Data Sources

1. Building footprints supplied by City of Vancouver.
2. 2015 orthophoto supplied by City of Vancouver.
3. Inset basemap from National Geographic and Esri.

References

1. NHC (2019). Central Waterfront District Sea Level Rise and Flood Risk (Draft Report) prepared for the Vancouver Fraser Port Authority.
2. Ausenco-Sandwell (2011). Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use: Guidelines for Management of Coastal Flood Hazard Land Use. Prepared by Ausenco-Sandwell for BC Ministry of Environment.

Disclaimer

PORT of vancouver

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SCALE - 1:60,000
0 1 2 3 KM
N

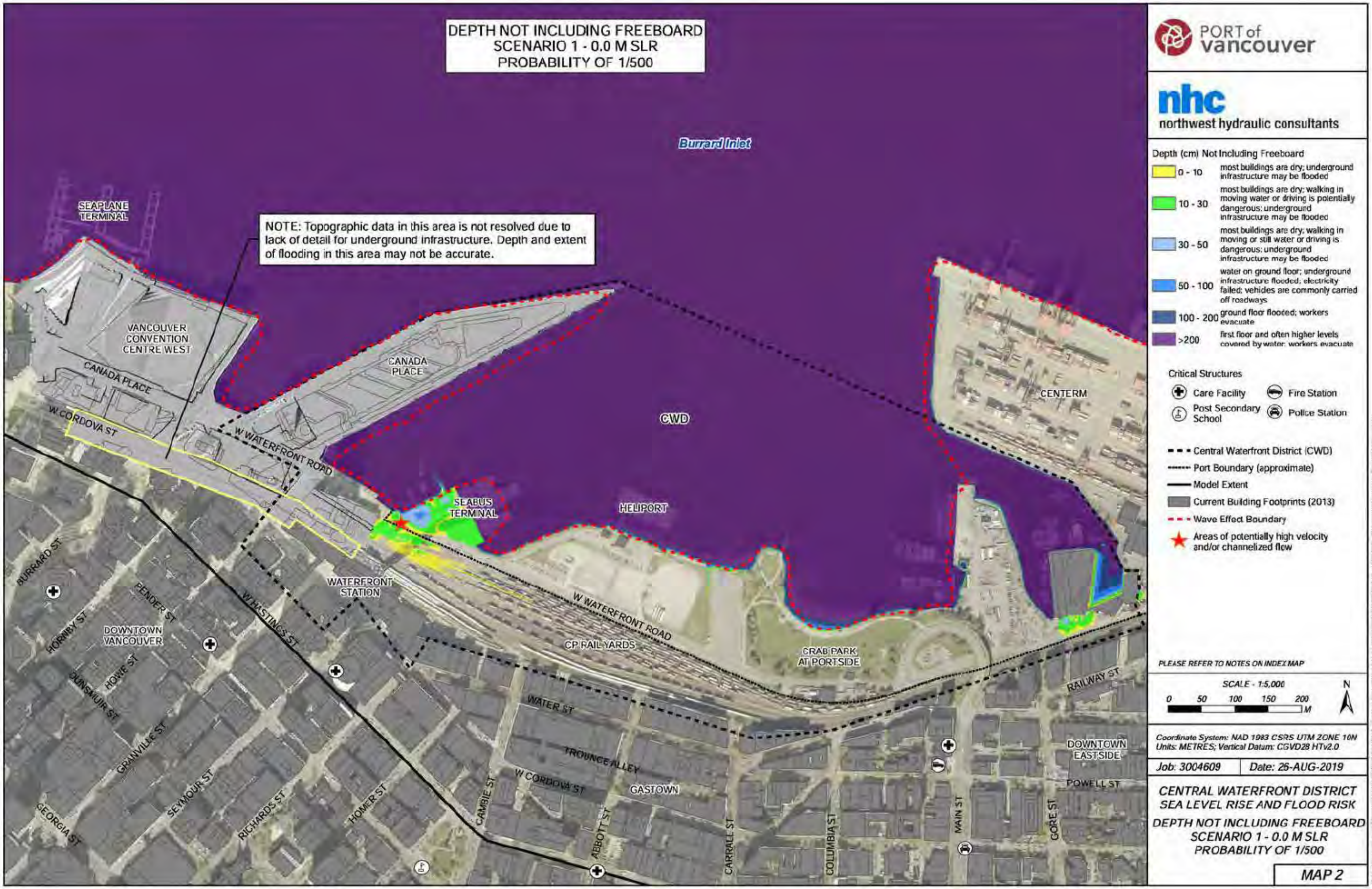
Coordinate System: NAD 1983 CSRS UTM ZONE 10N
Units: METRES; Vertical Datum: CGVD28 HTv2.0

Job: 3004609 | Date: 26-AUG-2019

CENTRAL WATERFRONT DISTRICT
SEA LEVEL RISE AND FLOOD RISK

FLOOD MAPPING INDEX

MAP 1


DEPTH NOT INCLUDING FREEBOARD
SCENARIO 1 - 0.0 M SLR
PROBABILITY OF 1/500
Burrard Inlet
SEAPLANE TERMINAL
NOTE: Topographic data in this area is not resolved due to lack of detail for underground infrastructure. Depth and extent of flooding in this area may not be accurate.
VANCOUVER CONVENTION CENTRE WEST
CANADA PLACE
CANADA PLACE
W CORDOVA ST
W WATERFRONT ROAD
CWD
CENTERM
SEABUS TERMINAL
HELIPORT
WATERFRONT STATION
W WATERFRONT ROAD
CP RAIL YARDS
CRAB PARK AT PORTSIDE
RAILWAY ST
BURRARD ST
PENDER ST
HORNBY ST
DOWNTOWN VANCOUVER
W HASTINGS ST
HOWE ST
DUNSMUIR ST
GRANVILLE ST
SEYMOUR ST
RICHARDS ST
HOMER ST
GEORGIA ST
CAMBIE ST
WATER ST
TROUNCE ALLEY
W CORDOVA ST
GASTOWN
ABBOTT ST
CARRALL ST
COLUMBIA ST
MAIN ST
GORE ST
DOWNTOWN EASTSIDE
POWELL ST
PORT of vancouver
nhc
northwest hydraulic consultants
Depth (cm) Not Including Freeboard
0 - 10 most buildings are dry; underground infrastructure may be flooded
10 - 30 most buildings are dry; walking in moving water or driving is potentially dangerous; underground infrastructure may be flooded
30 - 50 most buildings are dry; walking in moving or still water or driving is dangerous; underground infrastructure may be flooded
50 - 100 water on ground floor; underground infrastructure flooded; electricity failed; vehicles are commonly carried off roadways
100 - 200 ground floor flooded; workers evacuate
>200 first floor and often higher levels covered by water; workers evacuate
Critical Structures
Care Facility
Fire Station
Post Secondary School
Police Station
Central Waterfront District (CWD)
Port Boundary (approximate)
Model Extent
Current Building Footprints (2013)
Wave Effect Boundary
Areas of potentially high velocity and/or channelized flow
PLEASE REFER TO NOTES ON INDEX MAP
SCALE - 1:5,000
0 50 100 150 200 M
N
Coordinate System: NAD 1983 CSRS UTM ZONE 10N
Units: METRES; Vertical Datum: CGVD28 HTv2.0
Job: 3004609
Date: 26-AUG-2019
CENTRAL WATERFRONT DISTRICT
SEA LEVEL RISE AND FLOOD RISK
DEPTH NOT INCLUDING FREEBOARD
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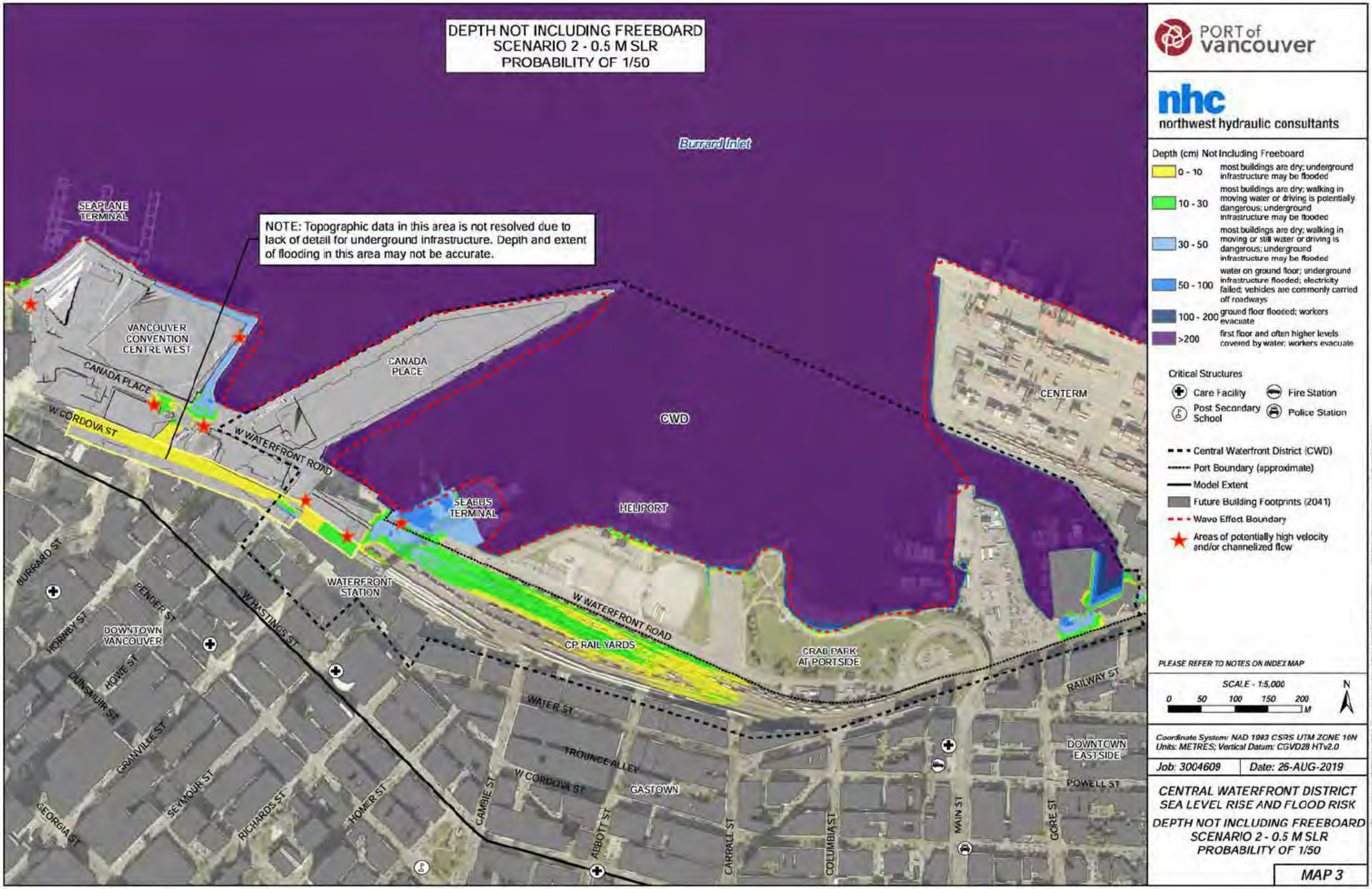
PROBABILITY OF 1/500
MAP 2


DEPTH NOT INCLUDING FREEBOARD
SCENARIO 2 - 0.5 M SLR
PROBABILITY OF 1/50
Burrard Inlet
NOTE: Topographic data in this area is not resolved due to lack of detail for underground infrastructure. Depth and extent of flooding in this area may not be accurate.
SEAPLANE TERMINAL
VANCOUVER CONVENTION CENTRE WEST
CANADA PLACE
CANADA PLACE
W CORDOVA ST
W WATERFRONT ROAD
CWD
CENTERM
SEABUS TERMINAL
HELIPORT
WATERFRONT STATION
W WATERFRONT ROAD
CP RAIL YARDS
CRAB PARK AT PORTSIDE
BURRARD ST
HORNBY ST
DOWNTOWN VANCOUVER
PENDER ST
W HASTINGS ST
DUNSMUIR ST
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Port Boundary (approximate)
Model Extent
Future Building Footprints (2041)
Wave Effect Boundary
Areas of potentially high velocity and/or channelized flow
PLEASE REFER TO NOTES ON INDEX MAP
SCALE - 1:5,000
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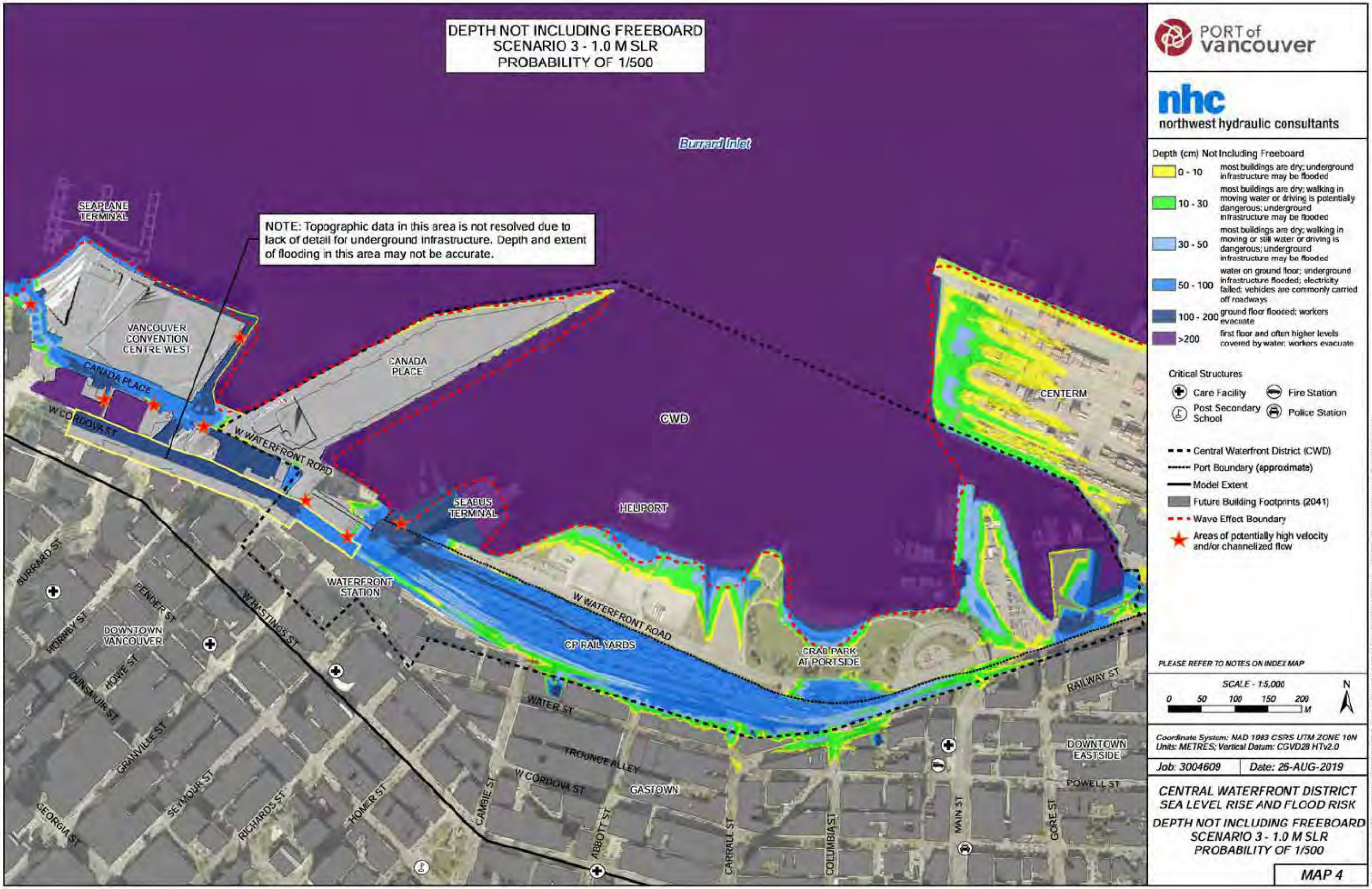
N
Coordinate System: NAD 1983 CSRS UTM ZONE 10N
Units: METRES; Vertical Datum: CGVD28 HTv2.0
Job: 3004609
Date: 26-AUG-2019
CENTRAL WATERFRONT DISTRICT
SEA LEVEL RISE AND FLOOD RISK
DEPTH NOT INCLUDING FREEBOARD
SCENARIO 2 - 0.5 M SLR
PROBABILITY OF 1/50
MAP 3


DEPTH NOT INCLUDING FREEBOARD
SCENARIO 3 - 1.0 M SLR
PROBABILITY OF 1/500
Burrard Inlet
NOTE: Topographic data in this area is not resolved due to lack of detail for underground infrastructure. Depth and extent of flooding in this area may not be accurate.
SEAPLANE TERMINAL
VANCOUVER CONVENTION CENTRE WEST
CANADA PLACE
CANADA PLACE
W CORDOVA ST
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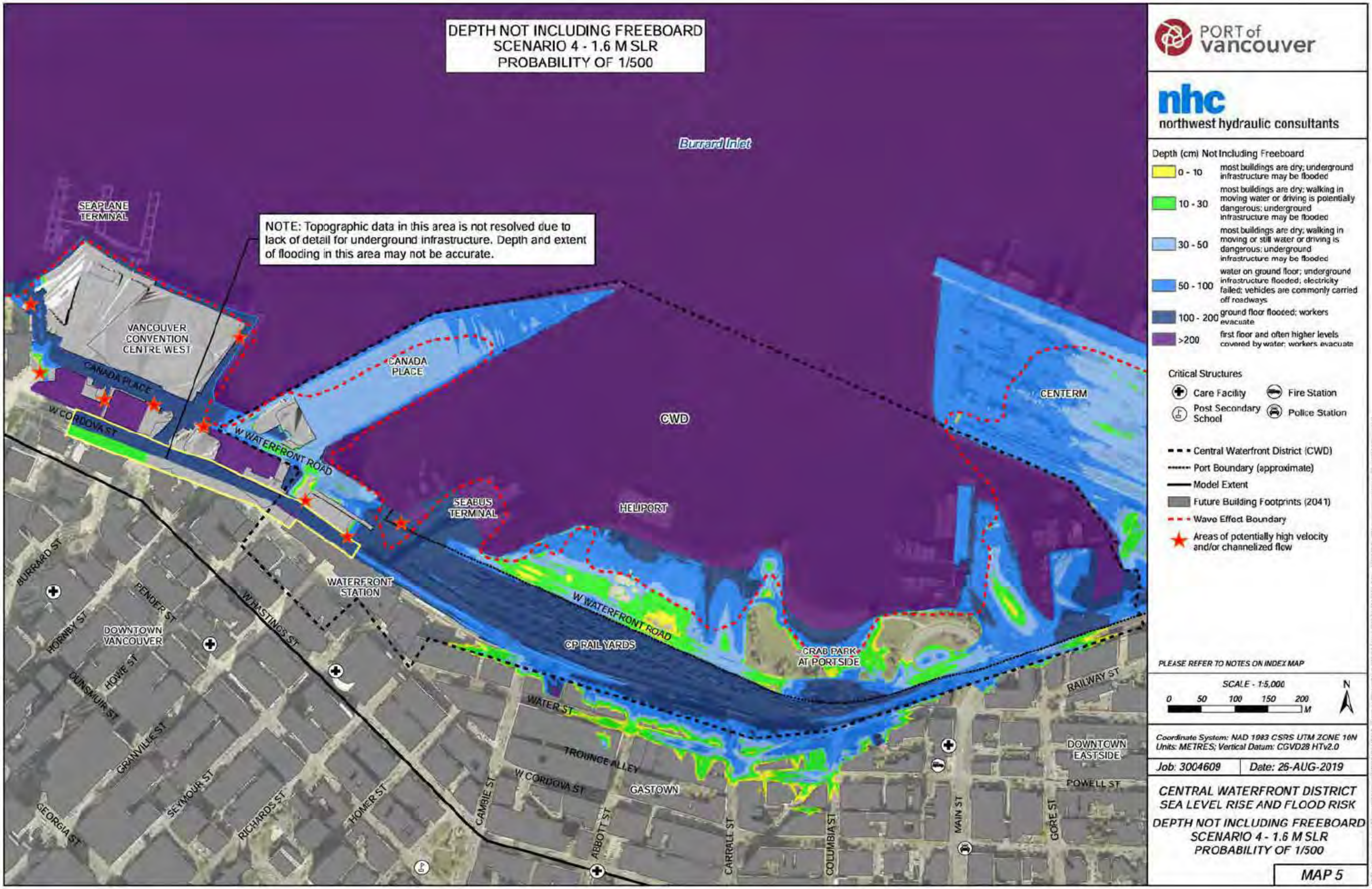
CENTRAL WATERFRONT DISTRICT
SEA LEVEL RISE AND FLOOD RISK
DEPTH NOT INCLUDING FREEBOARD
SCENARIO 3 - 1.0 M SLR
PROBABILITY OF 1/500
MAP 4


DEPTH NOT INCLUDING FREEBOARD
SCENARIO 4 - 1.6 M SLR
PROBABILITY OF 1/500
Burrard Inlet
NOTE: Topographic data in this area is not resolved due to lack of detail for underground infrastructure. Depth and extent of flooding in this area may not be accurate.
SEAPLANE TERMINAL
VANCOUVER CONVENTION CENTRE WEST
CANADA PLACE
CANADA PLACE
W CORDOVA ST
W WATERFRONT ROAD
CWD
SEABUS TERMINAL
HELIPORT
CENTERM
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ABBOTT ST
CARRALL ST
COLUMBIA ST
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GORE ST
POWELL ST
DOWNTOWN EASTSIDE
PORT of vancouver
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northwest hydraulic consultants
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Police Station
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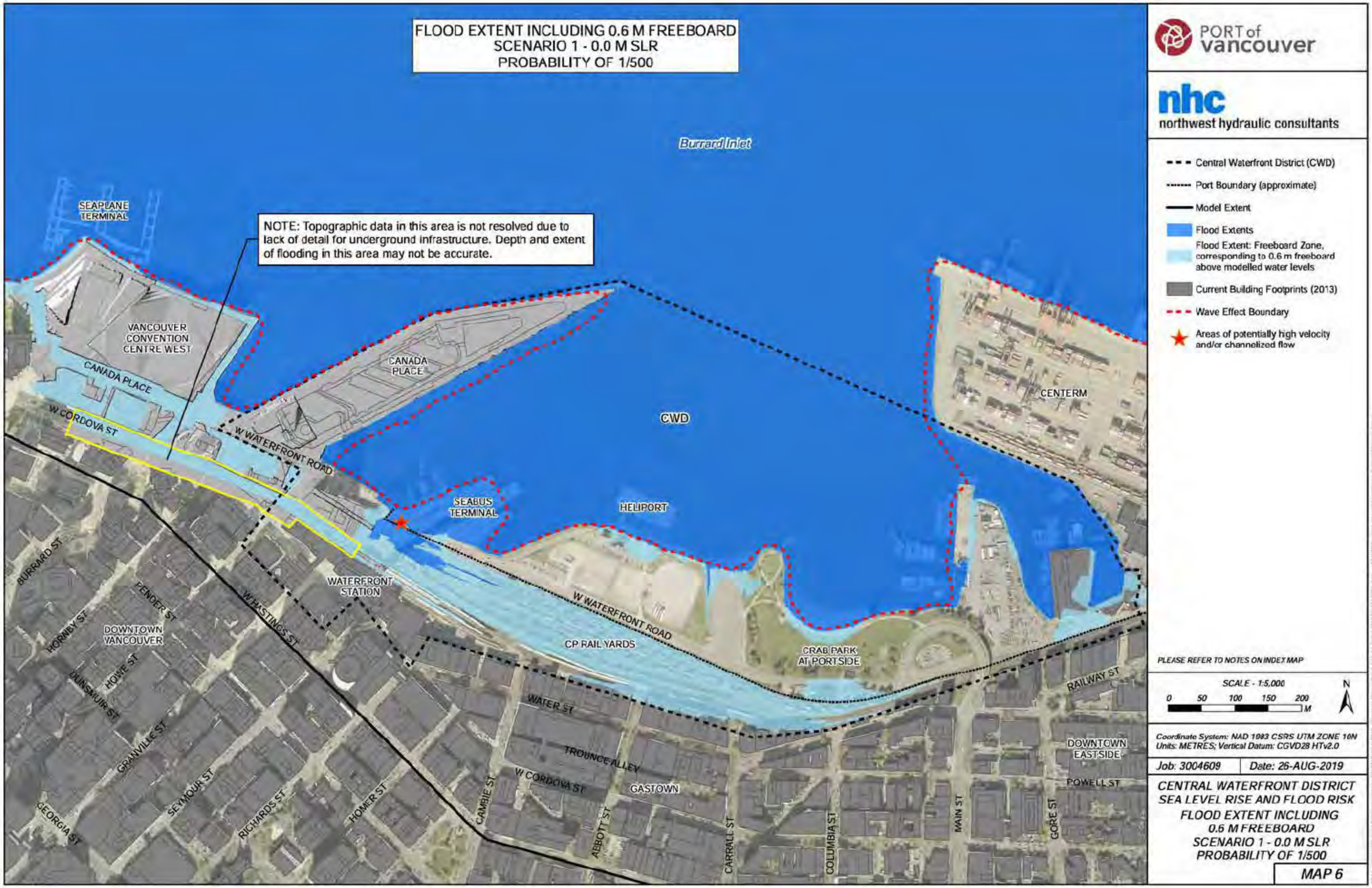
Port Boundary (approximate)
Model Extent
Future Building Footprints (2041)
Wave Effect Boundary
Areas of potentially high velocity and/or channelized flow
PLEASE REFER TO NOTES ON INDEX MAP
SCALE - 1:5,000
0 50 100 150 200 M
N
Coordinate System: NAD 1983 CSRS UTM ZONE 10N
Units: METRES; Vertical Datum: CGVD28 HTv2.0
Job: 3004609
Date: 26-AUG-2019
CENTRAL WATERFRONT DISTRICT
SEA LEVEL RISE AND FLOOD RISK
DEPTH NOT INCLUDING FREEBOARD
SCENARIO 4 - 1.6 M SLR
PROBABILITY OF 1/500
MAP 5



FLOOD EXTENT INCLUDING 0.6 M FREEBOARD
SCENARIO 1 - 0.0 M SLR
PROBABILITY OF 1/500
NOTE: Topographic data in this area is not resolved due to lack of detail for underground infrastructure. Depth and extent of flooding in this area may not be accurate.
Burrard Inlet
SEAPLANE TERMINAL
VANCOUVER CONVENTION CENTRE WEST
CANADA PLACE
CANADA PLACE
W CORDOVA ST
W WATERFRONT ROAD
CWD
CENTERM
SEABUS TERMINAL
HELIPORT
WATERFRONT STATION
W WATERFRONT ROAD
CP RAIL YARDS
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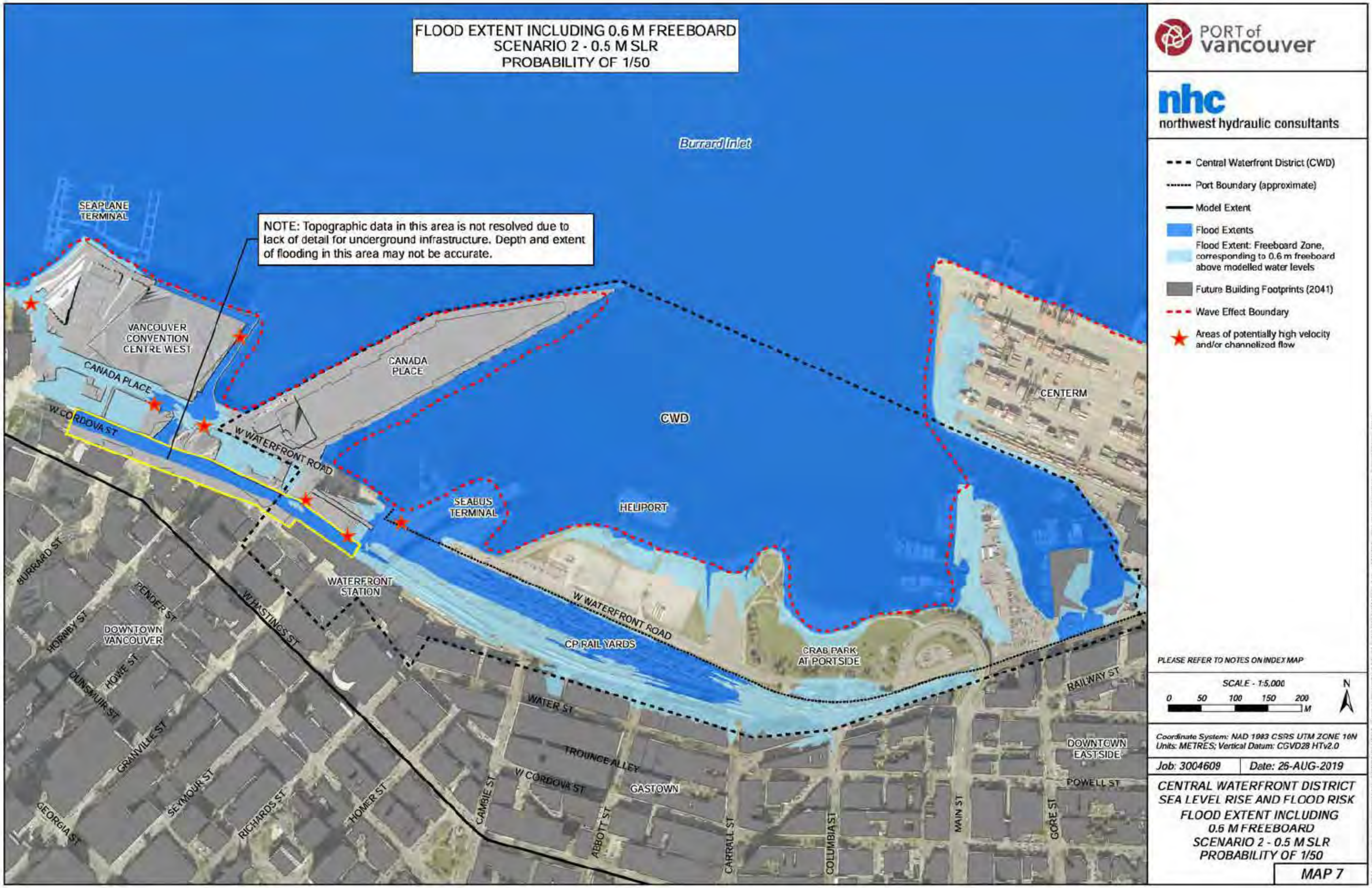
ABBOTT ST
CARRALL ST
COLUMBIA ST
MAIN ST
GORE ST
POWELL ST
DOWNTOWN EASTSIDE
PORT of vancouver
nhc
northwest hydraulic consultants
Central Waterfront District (CWD)
Port Boundary (approximate)
Model Extent
Flood Extents
Flood Extent: Freeboard Zone, corresponding to 0.6 m freeboard above modelled water levels
Current Building Footprints (2013)
Wave Effect Boundary
Areas of potentially high velocity and/or channelized flow
PLEASE REFER TO NOTES ON INDEX MAP
SCALE - 1:5,000
0 50 100 150 200 M
N
Coordinate System: NAD 1983 CSRS UTM ZONE 10N
Units: METRES; Vertical Datum: CGVD28 HTv2.0
Job: 3004609
Date: 26-AUG-2019
CENTRAL WATERFRONT DISTRICT
SEA LEVEL RISE AND FLOOD RISK
FLOOD EXTENT INCLUDING
0.6 M FREEBOARD
SCENARIO 1 - 0.0 M SLR
PROBABILITY OF 1/500
MAP 6


FLOOD EXTENT INCLUDING 0.6 M FREEBOARD
SCENARIO 2 - 0.5 M SLR
PROBABILITY OF 1/50
Burrard Inlet
NOTE: Topographic data in this area is not resolved due to lack of detail for underground infrastructure. Depth and extent of flooding in this area may not be accurate.
SEAPLANE TERMINAL
VANCOUVER CONVENTION CENTRE WEST
CANADA PLACE
CANADA PLACE
W CORDOVA ST
W WATERFRONT ROAD
CWD
SEABUS TERMINAL
HELIPORT
CENTERM
WATERFRONT STATION
W WATERFRONT ROAD
CP RAIL YARDS
CRAB PARK AT PORTSIDE
BURRARD ST
HORNBY ST
DOWNTOWN VANCOUVER
PENDER ST
W HASTINGS ST
HOWE ST
DUNSMUIR ST
GRANVILLE ST
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GEORGIA ST
RICHARDS ST
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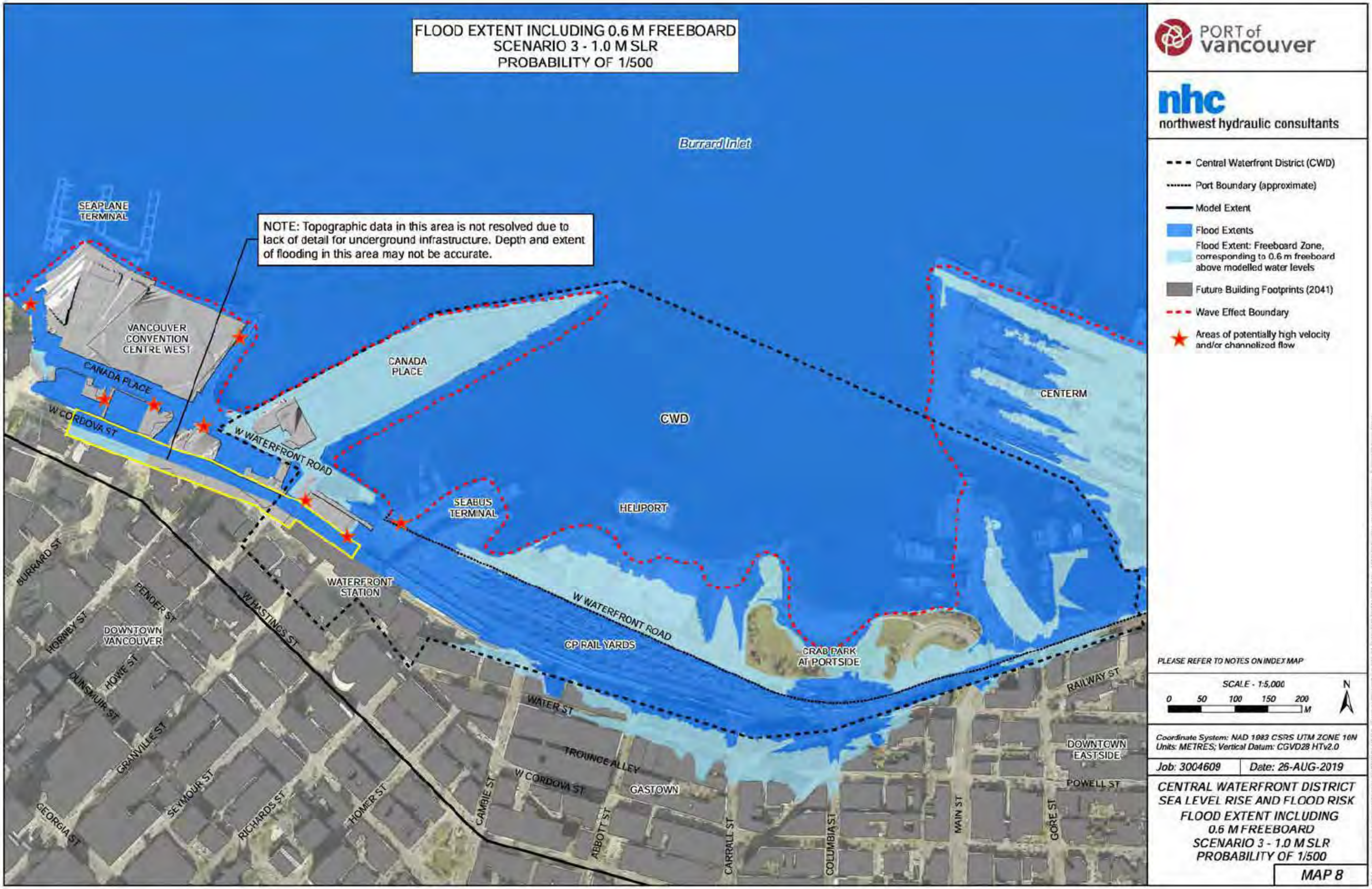
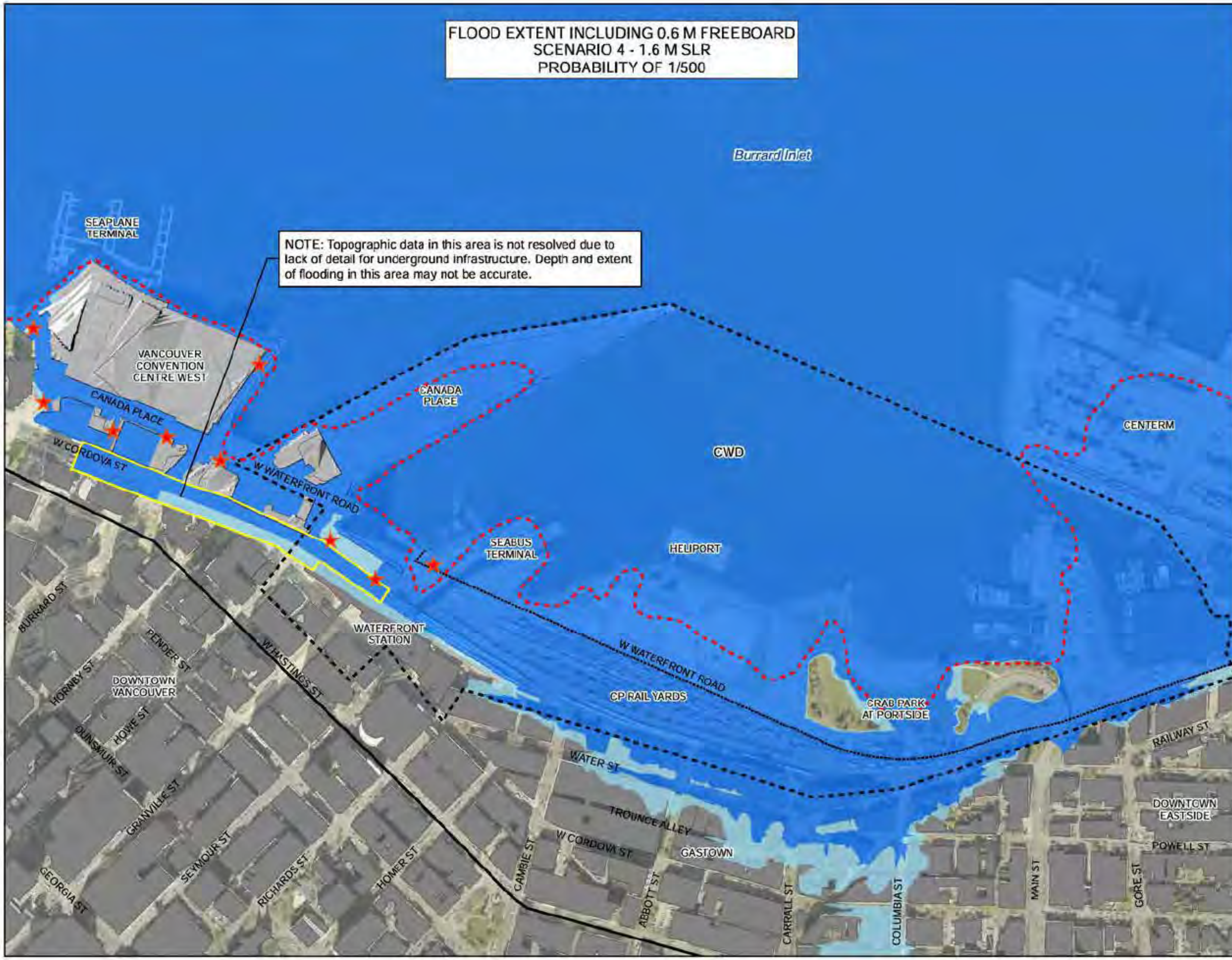
W CORDOVA ST
GASTOWN
ABBOTT ST
CARRALL ST
COLUMBIA ST
MAIN ST
GORE ST
RAILWAY ST
POWELL ST
DOWNTOWN EASTSIDE
PORT of vancouver
nhc
northwest hydraulic consultants
Central Waterfront District (CWD)
Port Boundary (approximate)
Model Extent
Flood Extents
Flood Extent: Freeboard Zone, corresponding to 0.6 m freeboard above modelled water levels
Future Building Footprints (2041)
Wave Effect Boundary
Areas of potentially high velocity and/or channelized flow
PLEASE REFER TO NOTES ON INDEX MAP
SCALE - 1:5,000
0 50 100 150 200 M
N
Coordinate System: NAD 1983 CSRS UTM ZONE 10N
Units: METRES; Vertical Datum: CGVD28 HTv2.0
Job: 3004609
Date: 26-AUG-2019
CENTRAL WATERFRONT DISTRICT
SEA LEVEL RISE AND FLOOD RISK
FLOOD EXTENT INCLUDING
0.6 M FREEBOARD
SCENARIO 2 - 0.5 M SLR
PROBABILITY OF 1/50
MAP 7


FLOOD EXTENT INCLUDING 0.6 M FREEBOARD
SCENARIO 3 - 1.0 M SLR
PROBABILITY OF 1/500
PORT of vancouver
nhc
northwest hydraulic consultants
Central Waterfront District (CWD)
Port Boundary (approximate)
Model Extent
Flood Extents
Flood Extent: Freeboard Zone, corresponding to 0.6 m freeboard above modelled water levels
Future Building Footprints (2041)
Wave Effect Boundary
Areas of potentially high velocity and/or channelized flow
Burrard Inlet
NOTE: Topographic data in this area is not resolved due to lack of detail for underground infrastructure. Depth and extent of flooding in this area may not be accurate.
SEAPLANE TERMINAL
VANCOUVER CONVENTION CENTRE WEST
CANADA PLACE
CANADA PLACE
W CORDOVA ST
W WATERFRONT ROAD
CWD
CENTERM
SEABUS TERMINAL
HELIPORT
WATERFRONT STATION
W WATERFRONT ROAD
CP RAIL YARDS
CRAB PARK AT PORTSIDE
BURRARD ST
PENDER ST
W HASTINGS ST
DOWNTOWN VANCOUVER
HORNBY ST
HOWE ST
DUNSMUIR ST
GRANVILLE ST
SEYMOUR ST
RICHARDS ST
HOMER ST
GEORGIA ST
WATER ST
TROUNCE ALLEY
W CORDOVA ST
GASTOWN
CAMBIE ST
ABBOTT ST
CARRALL ST
COLUMBIA ST
MAIN ST
GORE ST
RAILWAY ST
DOWNTOWN EASTSIDE
POWELL ST
PLEASE REFER TO NOTES ON INDEX MAP
SCALE - 1:5,000
0 50 100 150 200 M
N
Coordinate System: NAD 1983 CSRS UTM ZONE 10N
Units: METRES; Vertical Datum: CGVD28 HTv2.0
Job: 3004609
Date: 26-AUG-2019
CENTRAL WATERFRONT DISTRICT
SEA LEVEL RISE AND FLOOD RISK
FLOOD EXTENT INCLUDING
0.6 M FREEBOARD
SCENARIO 3 - 1.0 M SLR
PROBABILITY OF 1/500
MAP 8



PORT of vancouver

nhc northwest hydraulic consultants

- Central Waterfront District (CWD)
- Port Boundary (approximate)
- Model Extent
- Flood Extents
- Flood Extent: Freeboard Zone, corresponding to 0.6 m freeboard above modelled water levels
- Future Building Footprints (2041)
- Wave Effect Boundary
- Areas of potentially high velocity and/or channelized flow

PLEASE REFER TO NOTES ON INDEX MAP

SCALE - 1:5,000

0 50 100 150 200 M

N

Coordinate System: NAD 1983 CSRS UTM ZONE 10N
Units: METRES; Vertical Datum: CGVD28 HTv2.0

Job: 3004609	*Date: 26-AUG-2019*

CENTRAL WATERFRONT DISTRICT SEA LEVEL RISE AND FLOOD RISK FLOOD EXTENT INCLUDING 0.6 M FREEBOARD SCENARIO 4 - 1.6 M SLR PROBABILITY OF 1/500

MAP 9

APPENDIX B

Wave Model Results

Prepared By:

Edwin Wang

31 July 2019

TABLE OF CONTENTS

LIST OF FIGURES

1 INTRODUCTION AND LIMITATIONS

The Port of Vancouver wishes to better understand flood risk at the Central Waterfront District area. NHC has undertaken flood modelling for combinations of tides, storm surge, and sea level rise. Utilizing the water depths from this modelling the SWAN wave model was utilized to simulate wind storm events in Vancouver Harbour to determine the potential maximum wave heights in the project area at the time of a high water event.

The wave model utilized the bare-earth DEM (Digital Elevation Model) that was used for the flood inundation modelling. Some structural details and buildings are not accounted for in this DEM. Known short-comings include:

- Seaplane floats and docks at the Vancouver Convention Centre West are not included in the model. These will provide some sheltering of waves propagating into Coal Harbour area.
- The Helijet float is not included in the model. This will provide some level of wave attenuation that is not reflected in the model.
- The flooding inundation model DEM set the 4K level of Canada Place as a solid level. As such, the Point of Canada Place is modelled as a solid structure and not as a pile supported structure. As water levels are at or near the crest of this structure the wave attenuation is deemed reasonable for some aspects of wave transmission at low water levels would not be properly simulated in the case of wave energy travelling below the deck.
- The SeaBus terminal provides wave attenuation that was deemed important to the study area. The floating terminal was included as a wave attenuation float with 5% wave transmission.
- Cargo containers at Centerm and Vanterm terminals are not included in the model. This will provide some level of wave attenuation that is not reflected in the model.
- Small fences, jersey barriers, and curbs are below the resolution of the SWAN model, and are not captured.

2 WAVE MODEL RESULTS

Six storm events are considered for each of the four water level scenarios:

1. Northwesterly winds from 293 degrees (True)
2. Northwesterly winds from 315 degrees (True)
3. Northwesterly winds from 337 degrees (True)
4. Northeasterly winds from 23 degrees (True)
5. Northeasterly winds from 45 degrees (True)
6. Northeasterly winds from 67 degrees (True)

The model result are presented in the following subsections. Two percent exceedance wave height ($H_{2\%}$) distributions are shown with coloured shading, and wave direction and relative heights are shown with vectors. The vectors are shown for every 10 grid cells (equivalent to 100 m apart).

In the previous NHC study for the City of Vancouver (NHC, 2014), a “wave effect boundary” was shown on the flood maps to denote the landward extent of waves of a sufficient height to be of concern as a hazard. This criteria was selected based on a FEMA study (Federal Emergency Management Agency (FEMA), 2014) which notes that “Recent post disaster assessments and wave tank research have shown that waves as small as 1.5 feet (0.45 metres) can cause significant structural damage.” For planning purposes and to take a cautionary approach, the “wave effect boundary” is defined as smoothed representation of the 0.3 m $H_{2\%}$ contour in this study. This is represented as the purple line the figures.

2.1 Scenario 1

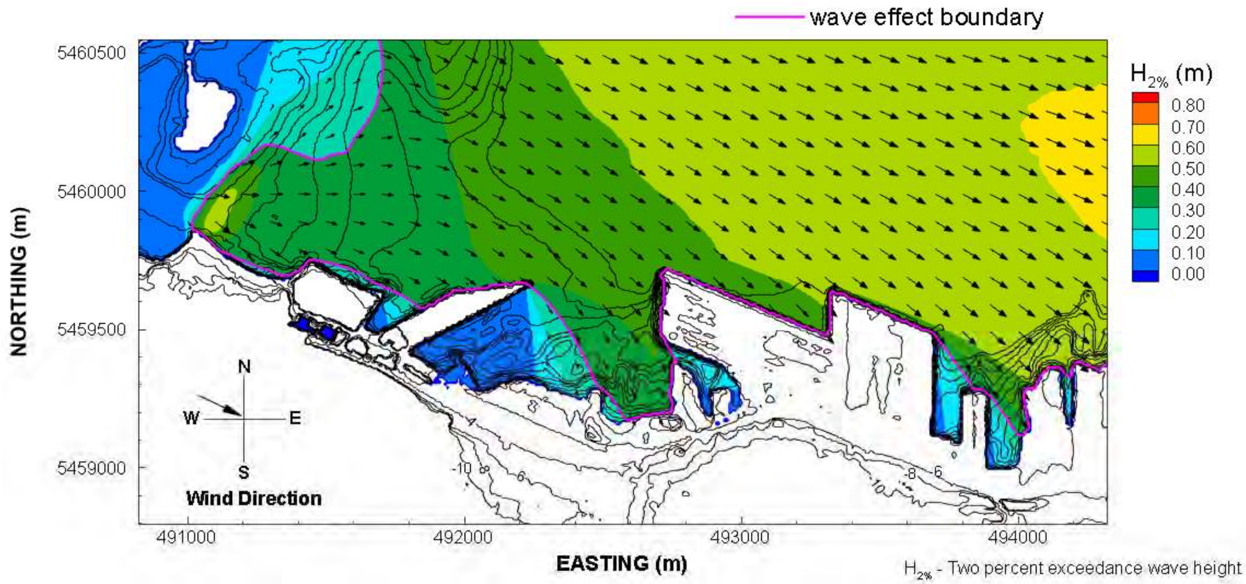


Figure 1 - Scenario 1 water level, and wind from NW at 293 degrees (True)

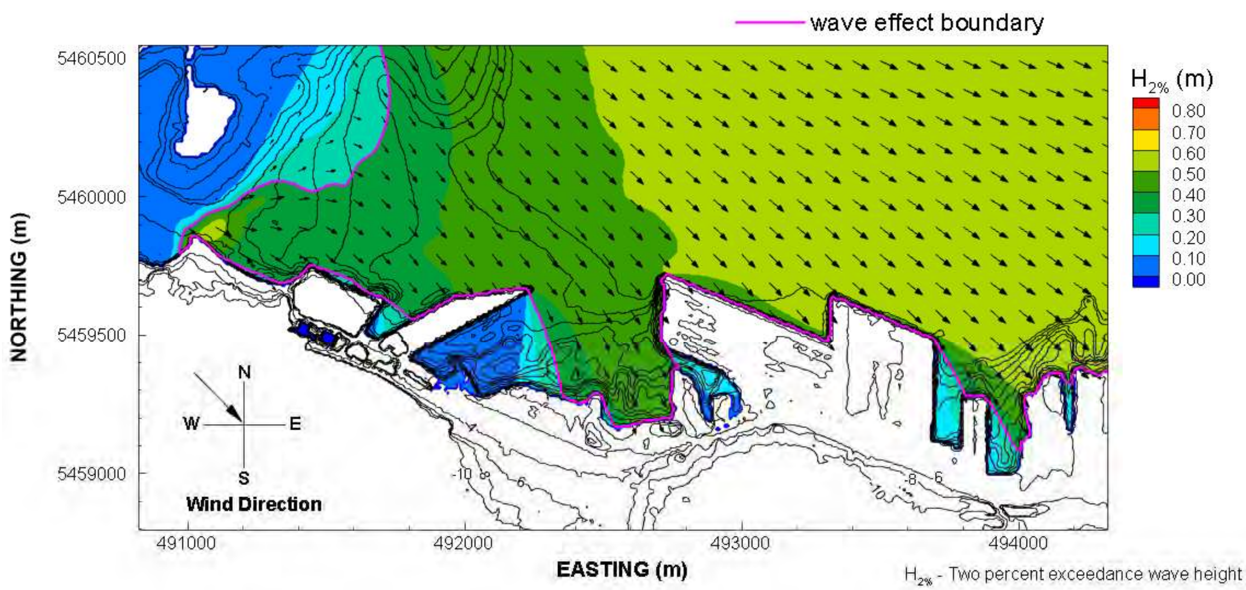


Figure 2 - Scenario 1 water level, and wind from NW at 315 degrees (True)

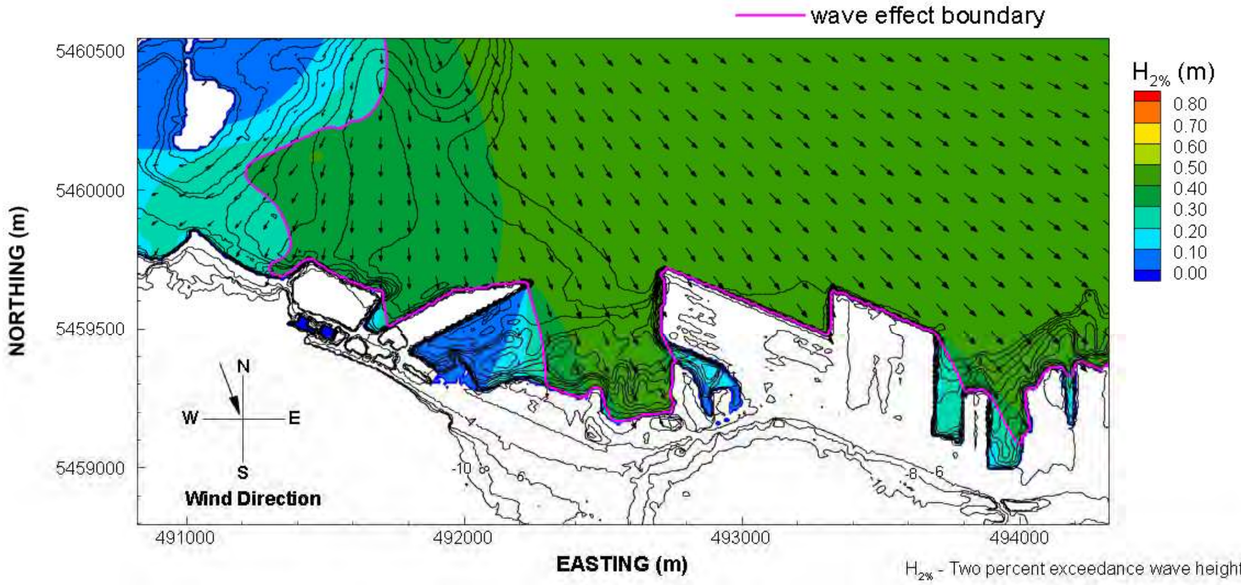


Figure 3 - Scenario 1 water level, and wind from NW at 337 degrees (True)

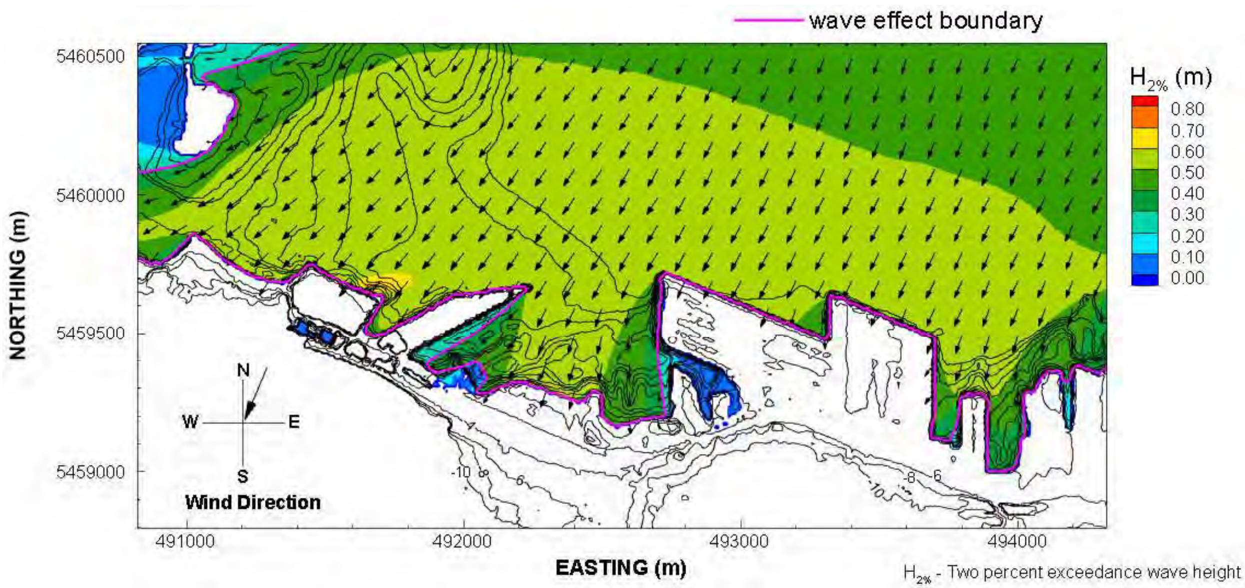


Figure 4 - Scenario 1 water level, and wind from NE at 23 degrees (True)

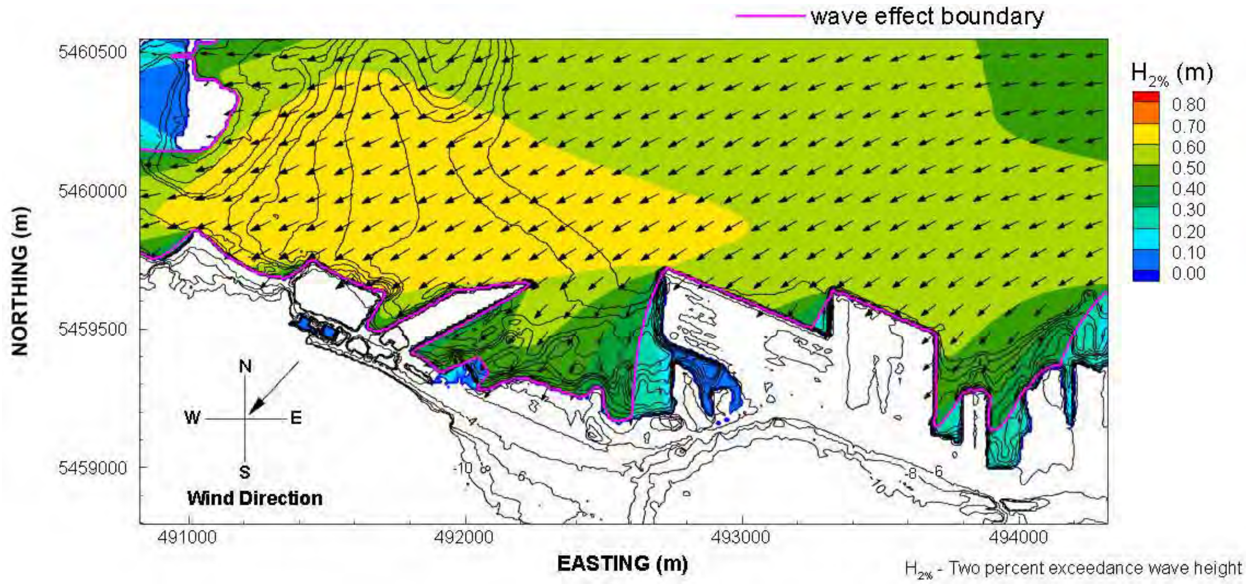


Figure 5 - Scenario 1 water level, and wind from NE at 45 degrees (True)

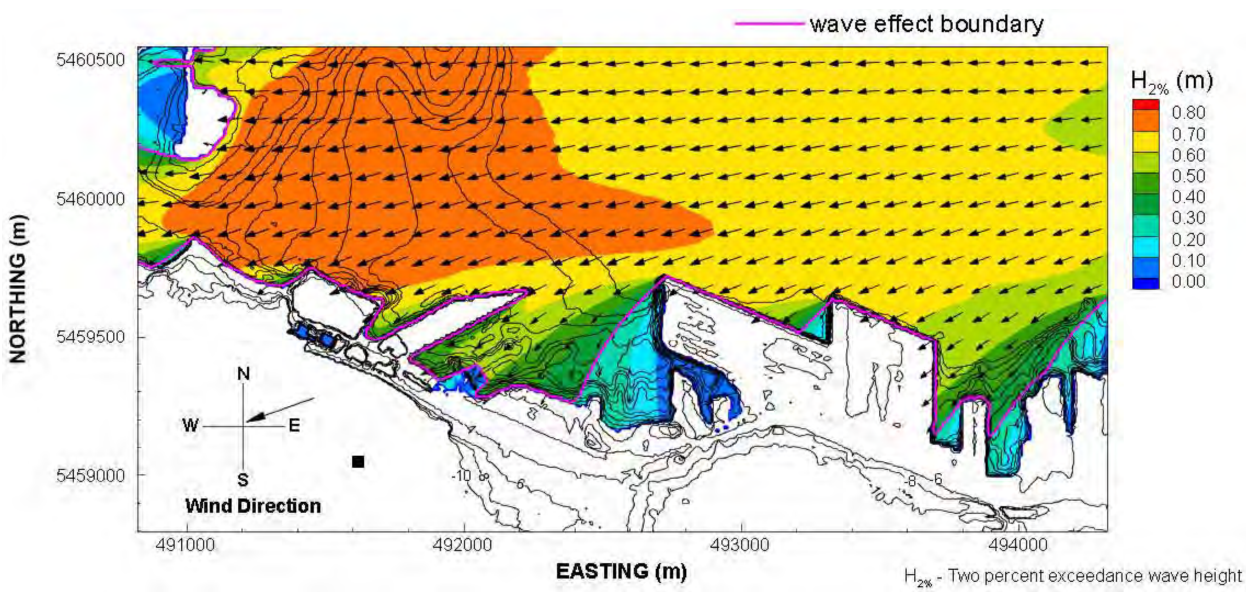


Figure 6 - Scenario 1 water level, and wind from NE at 67 degrees (True)

2.2 Scenario 2

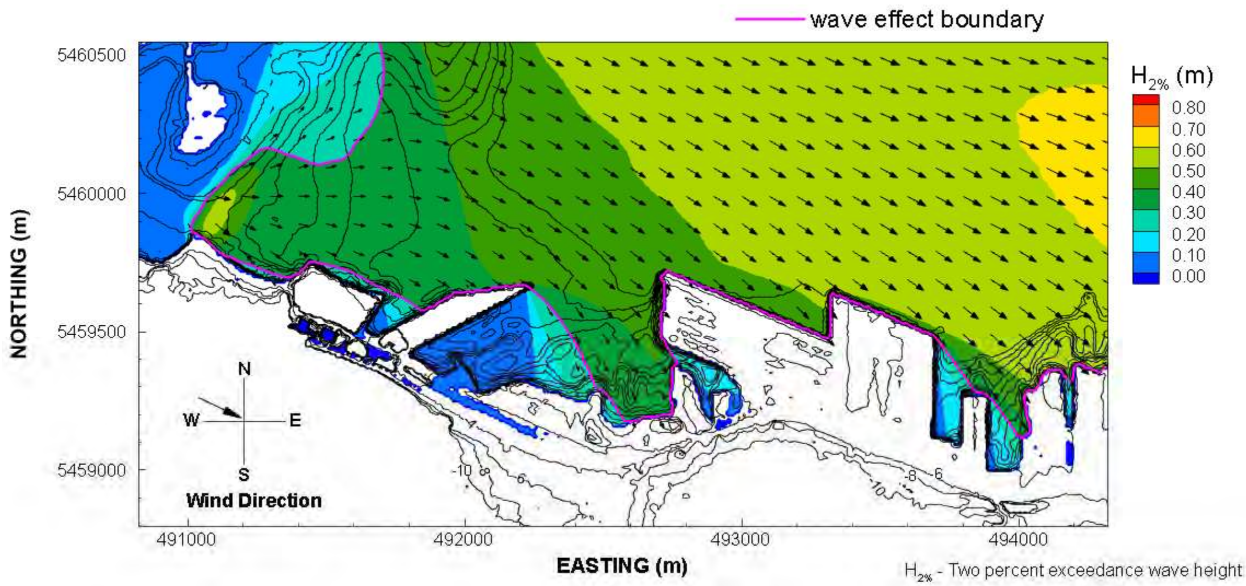


Figure 7 - Scenario 2 water level, and wind from NW at 293 degrees (True)

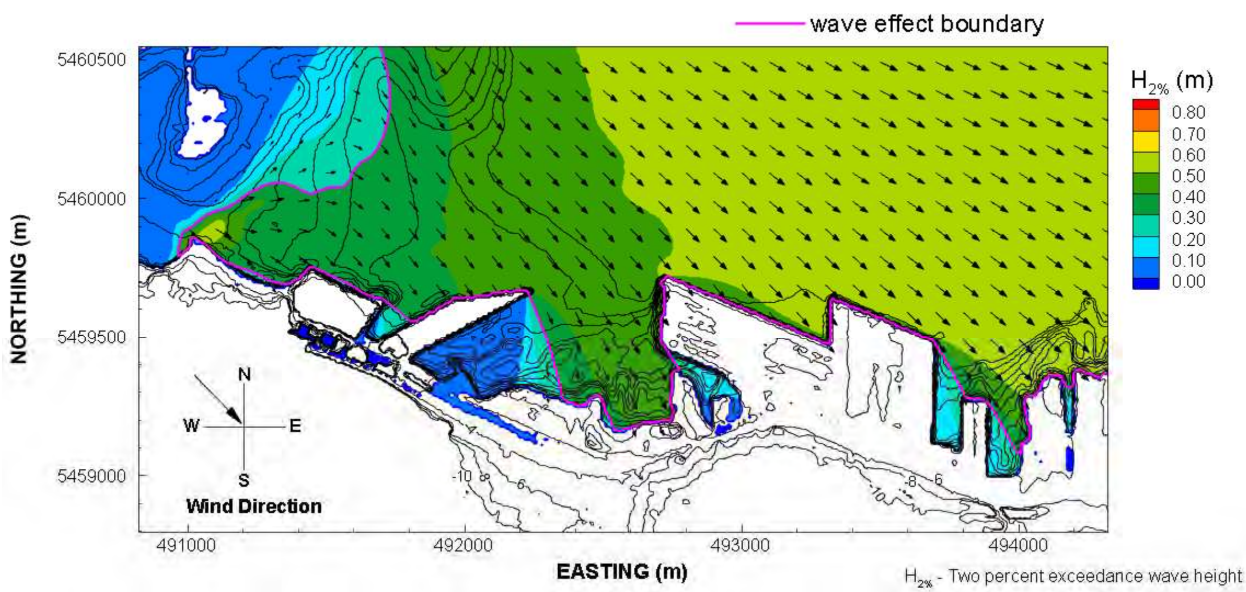


Figure 8 - Scenario 2 water level, and wind from NW at 315 degrees (True)

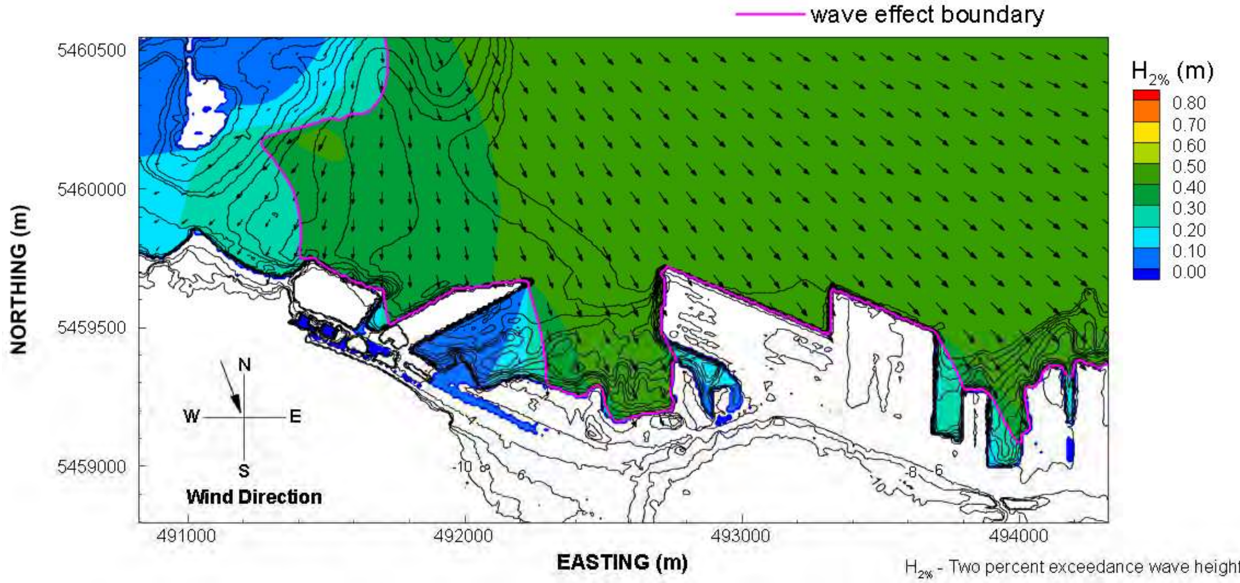


Figure 9 - Scenario 2 water level, and wind from NW at 337 degrees (True)

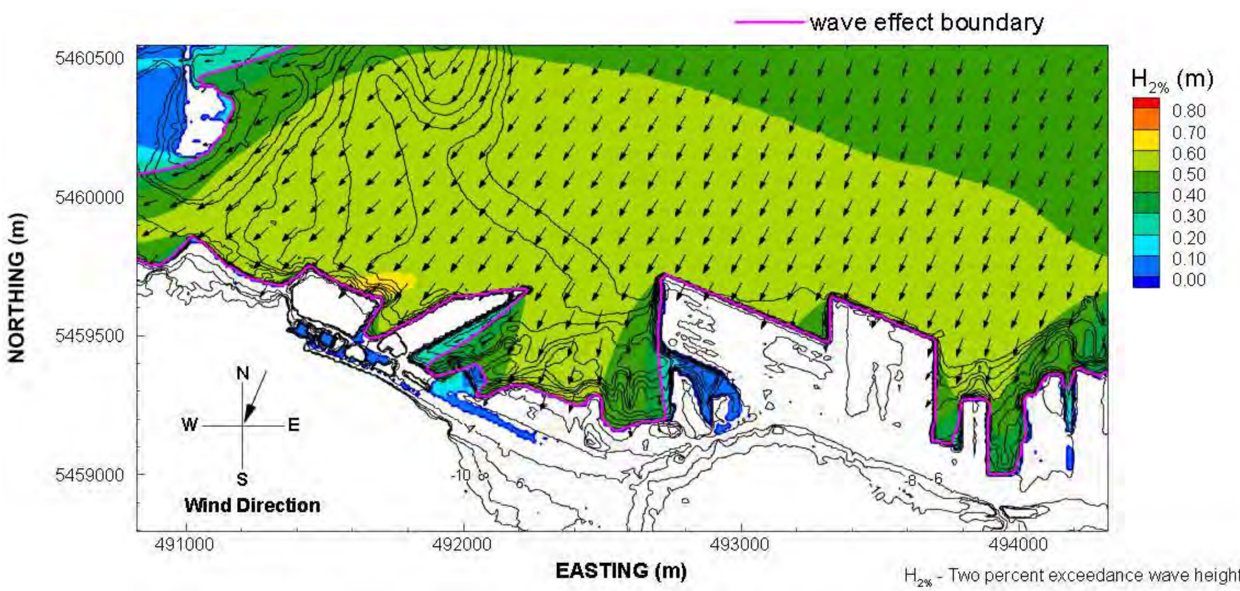


Figure 10 - Scenario 2 water level, and wind from NE at 23 degrees (True)

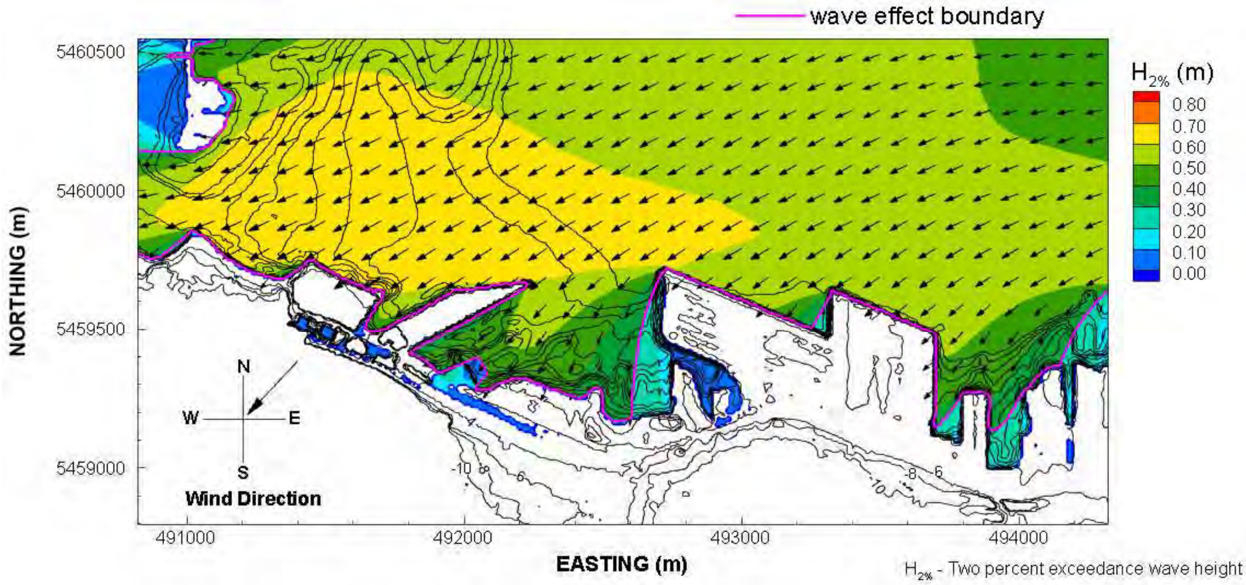


Figure 11 - Scenario 2 water level, and wind from NE at 45 degrees (True)

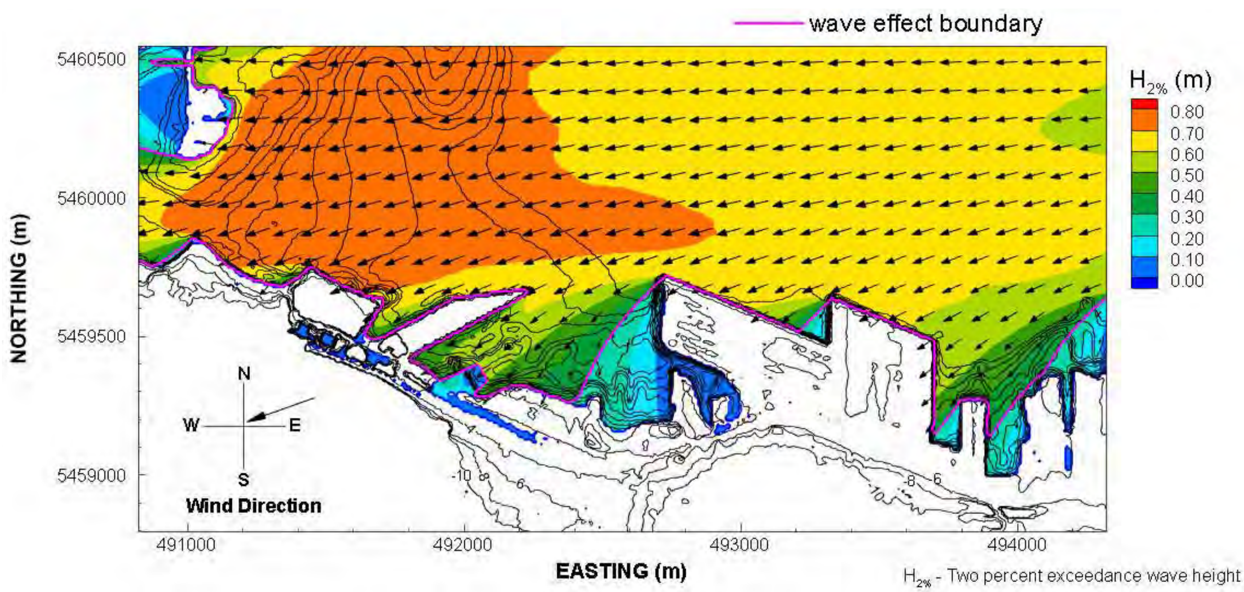


Figure 12 - Scenario 2 water level, and wind from NE at 67 degrees (True)

2.3 Scenario 3

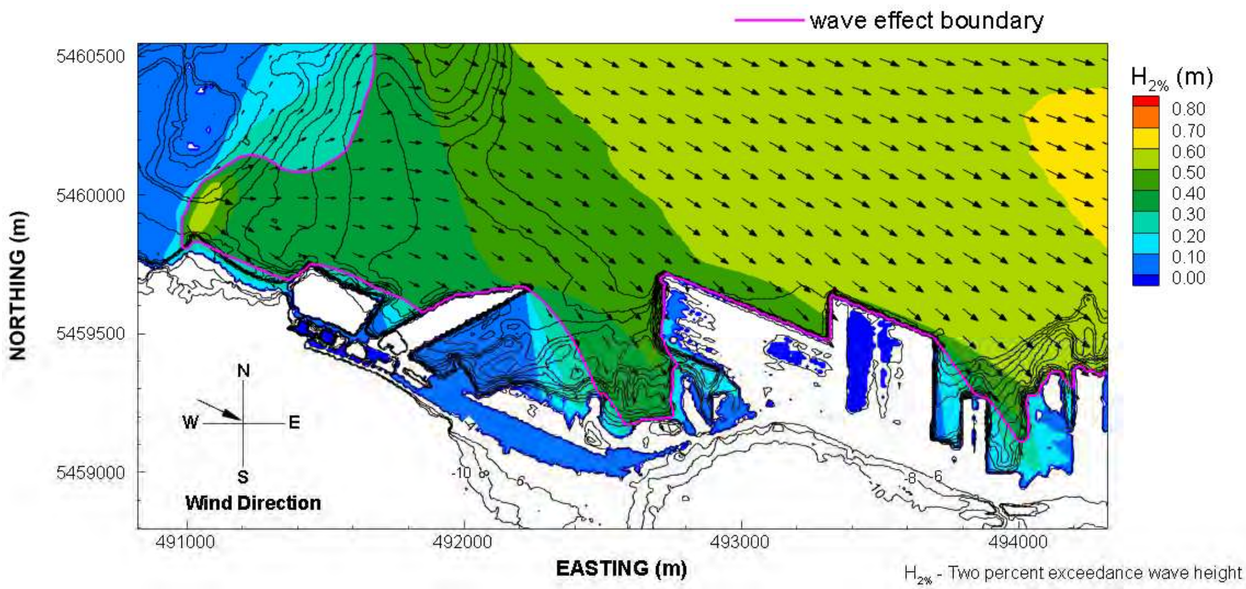


Figure 13 - Scenario 3 water level, and wind from NW at 293 degrees (True)

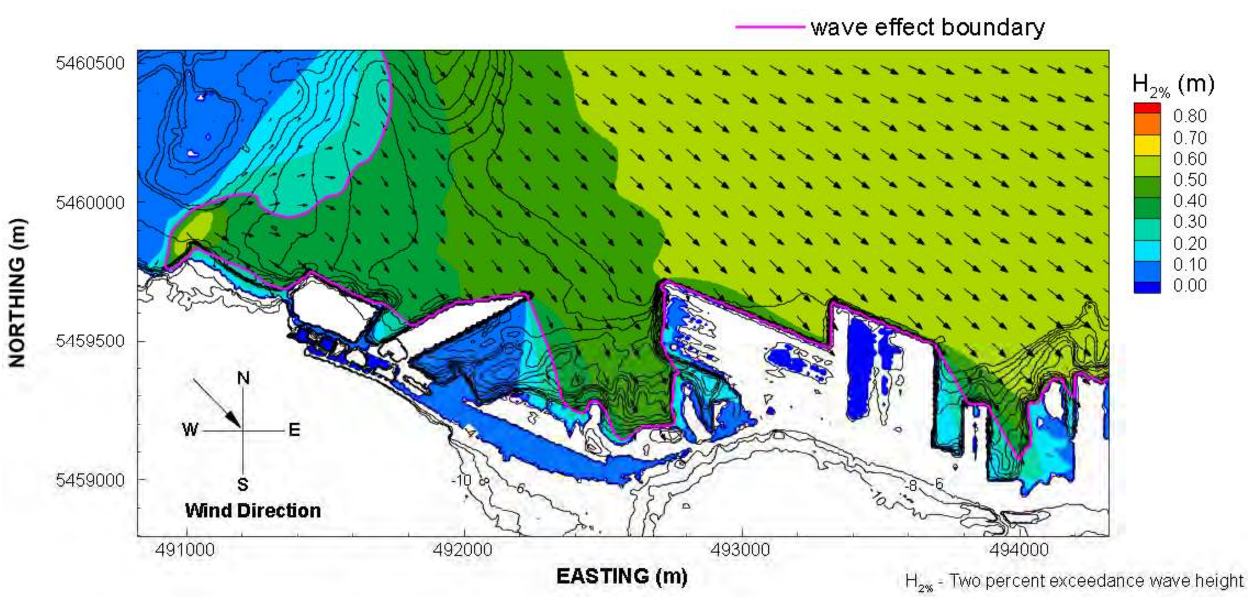


Figure 14 - Scenario 3 water level, and wind from NW at 315 degrees (True)

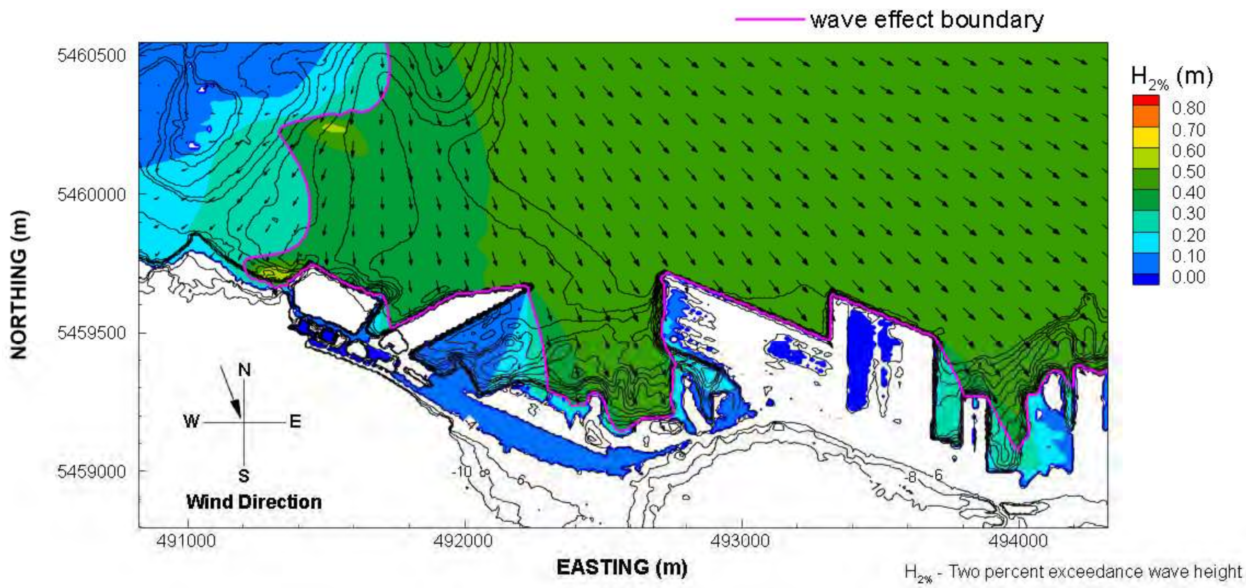


Figure 15 - Scenario 3 water level, and wind from NW at 337 degrees (True)

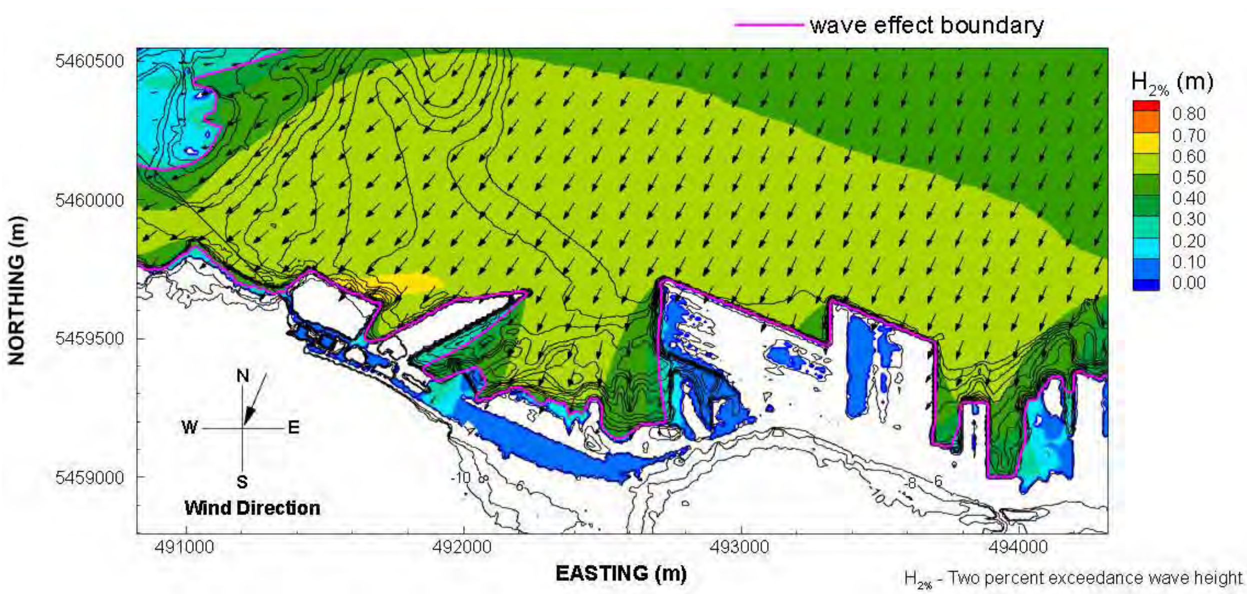


Figure 16 - Scenario 3 water level, and wind from NE at 23 degrees (True)

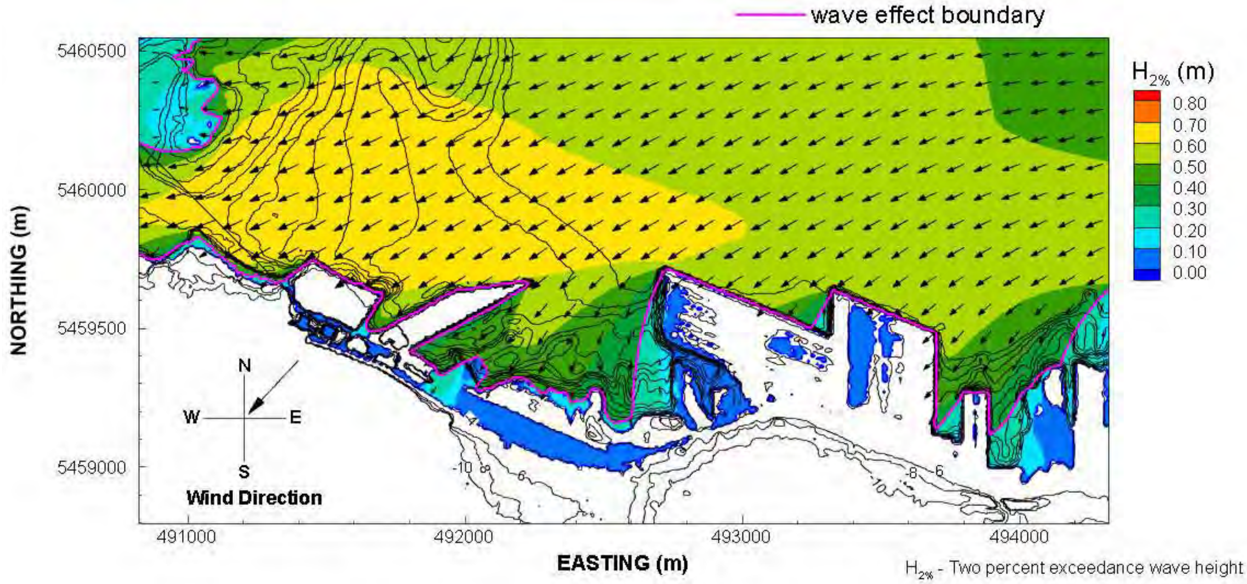


Figure 17 - Scenario 3 water level, and wind from NE at 45 degrees (True)

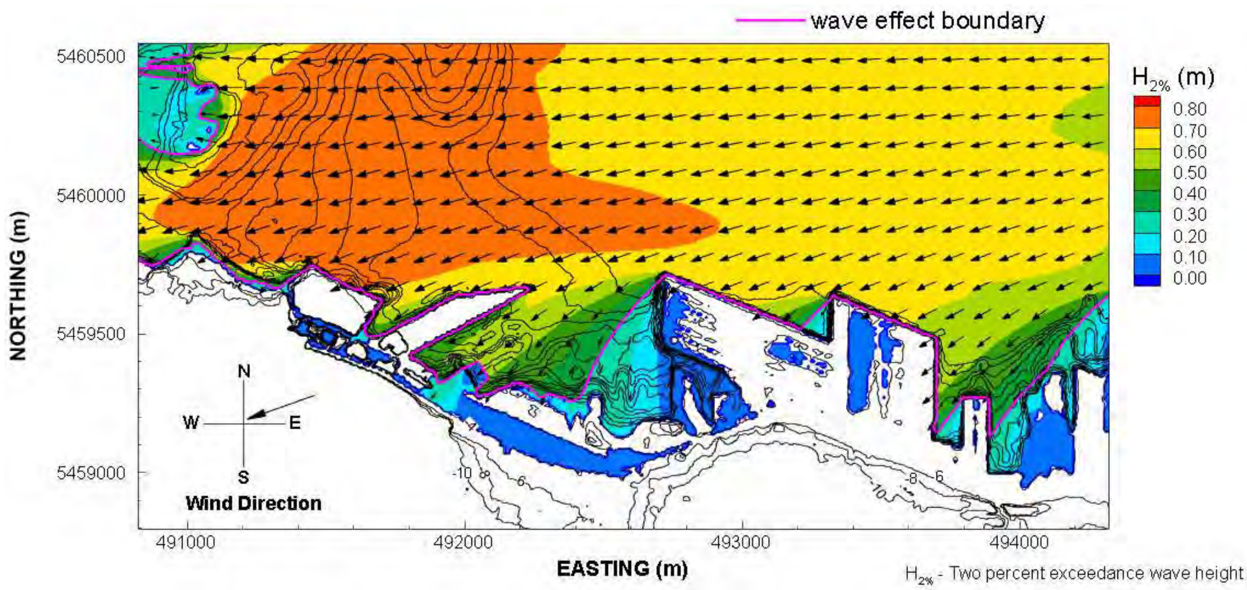


Figure 18 - Scenario 3 water level, and wind from NE at 67 degrees (True)

2.4 Scenario 4

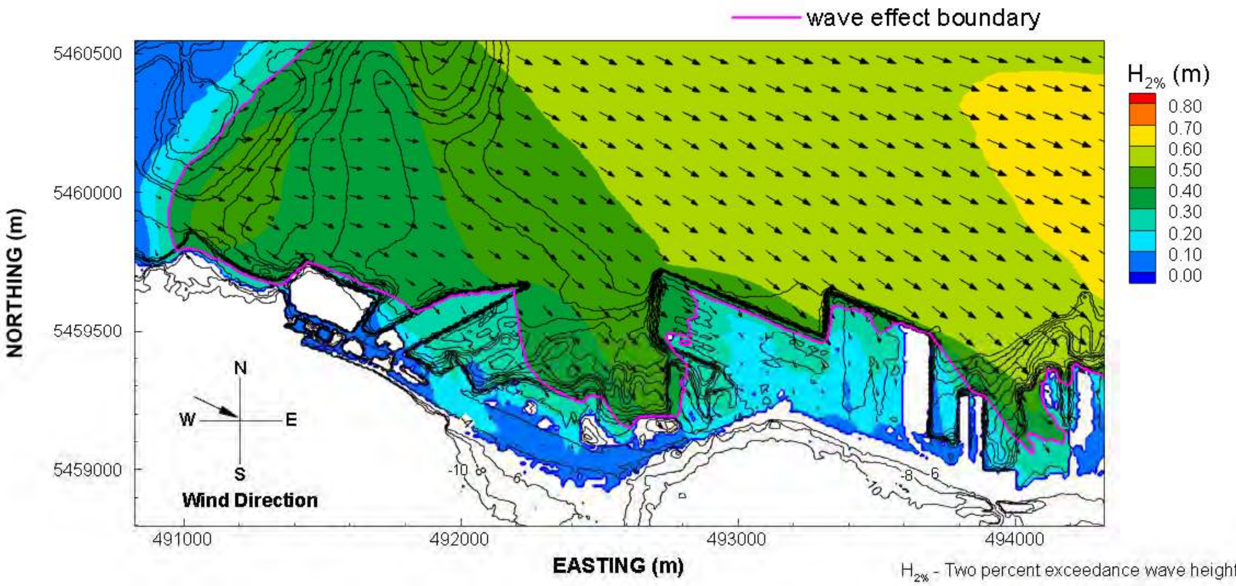


Figure 19 - Scenario 4 water level, and wind from NW at 293 degrees (True)

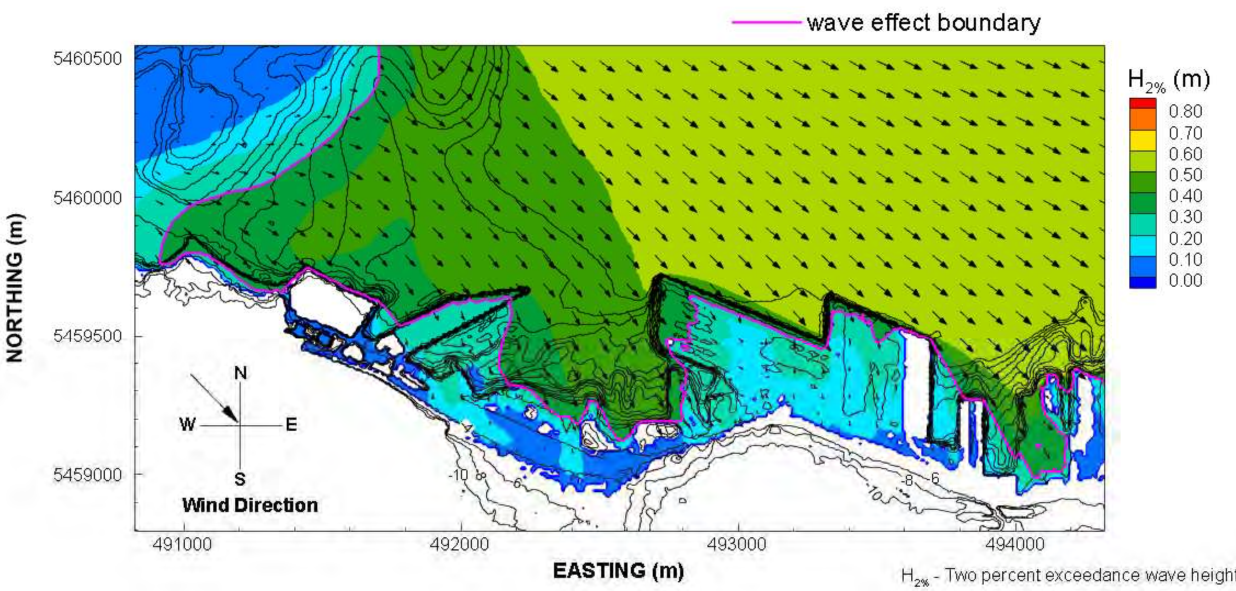


Figure 20 - Scenario 4 water level, and wind from NW at 315 degrees (True)

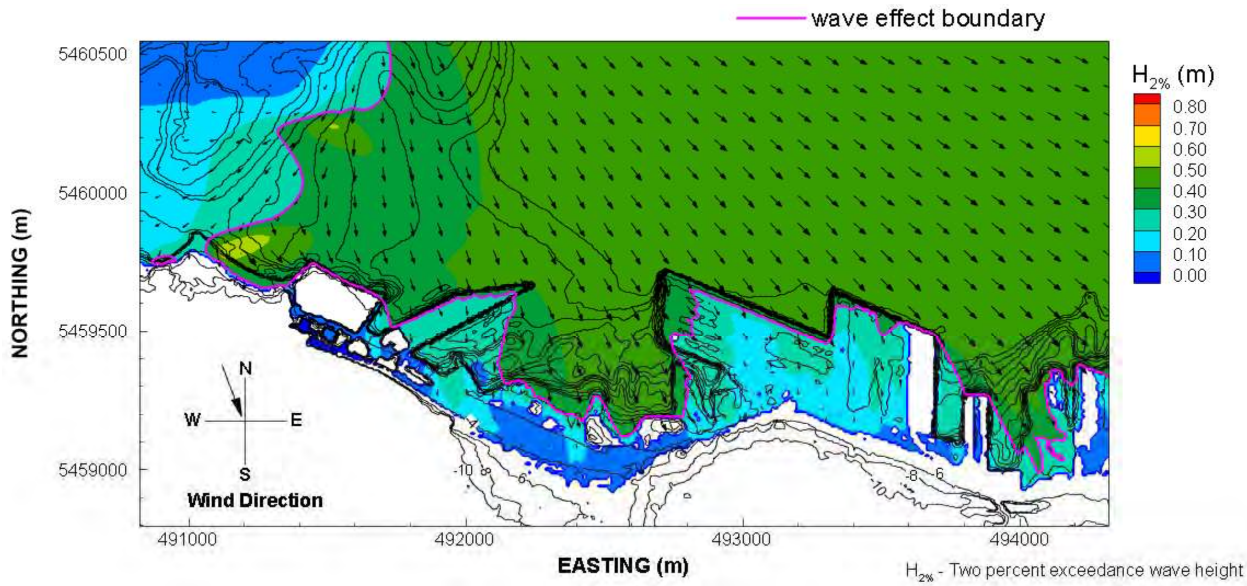


Figure 21 - Scenario 4 water level, and wind from NW at 337 degrees (True)

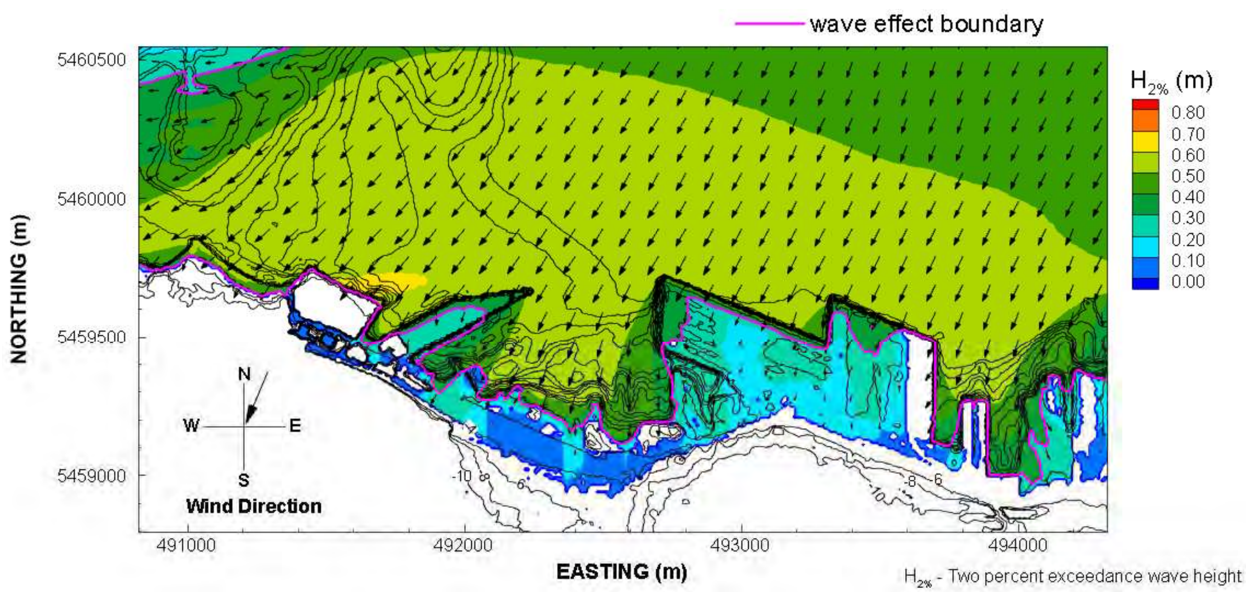


Figure 22 - Scenario 4 water level, and wind from NE at 23 degrees (True)

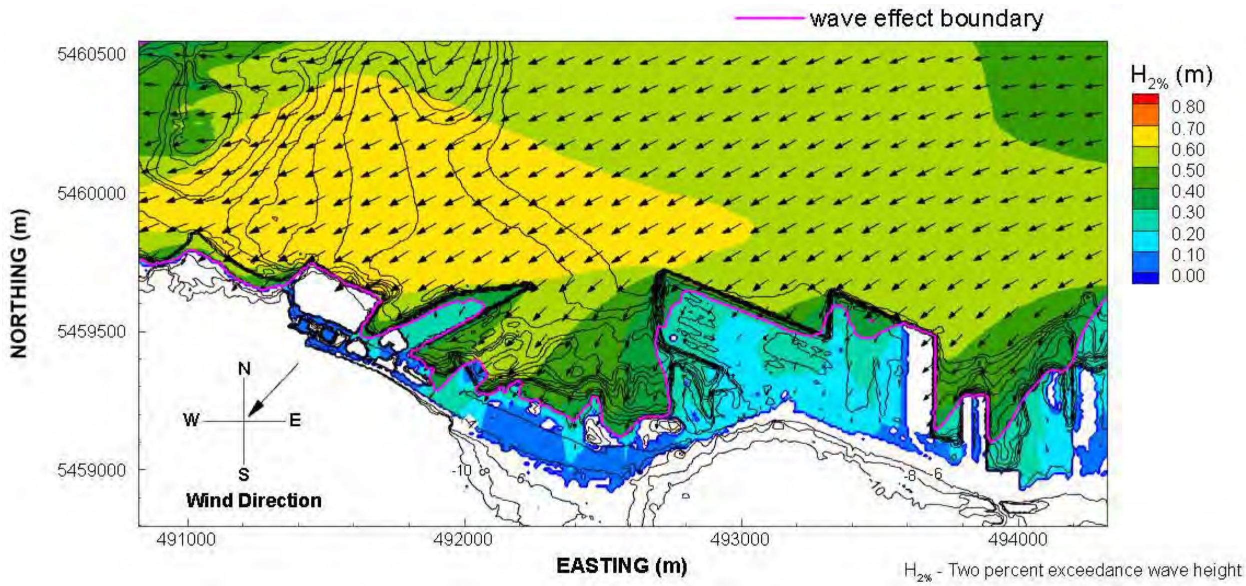


Figure 23 - Scenario 4 water level, and wind from NE at 45 degrees (True)

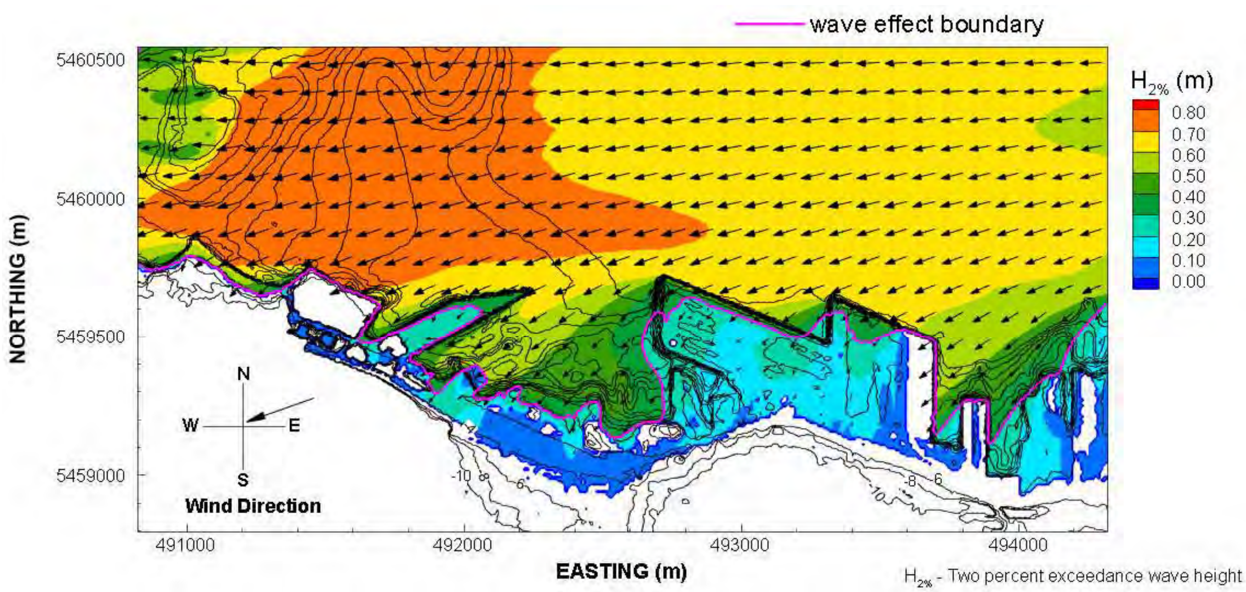


Figure 24 - Scenario 4 water level, and wind from NE at 67 degrees (True)

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