District of North Saanich

Flood Construction Levels for 0.5 m and 1.0 m Sea Level Rise

Prepared By: SNC-Lavalin Inc. 04 January 2017

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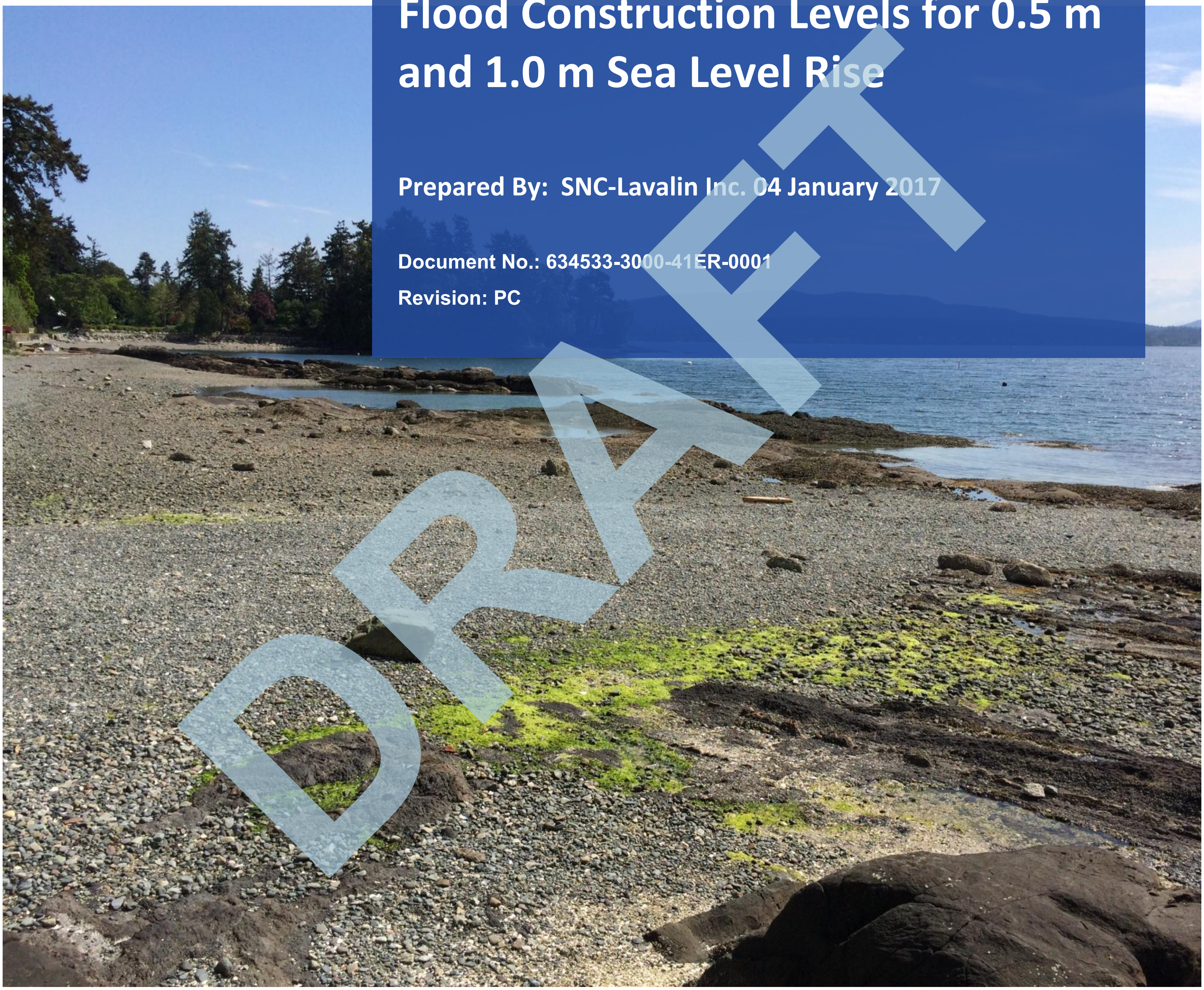


EXECUTIVE SUMMARY

Background

SNC-Lavalin was retained by the District of North Saanich (DNS) to review and refine Flood Construction Levels (FCLs) previously developed for the District of North Saanich by the CRD.

The existing CRD FCL estimate, for one meter of sea level rise, consists of a single value of 5.04 m relative to the present Canadian Geodetic Vertical Datum (CGVD28). The reference datum is notionally the same as mean sea level today.

The Flood Construction Level is defined as the underside elevation of a wooden floor system, or the top elevation of a concrete slab, for habitable buildings, and is calculated from the sum of the following components:

- The Designated Flood Level (DFL), which includes tide, storm surge, and sea level rise,
- The effects of waves at the shoreline during a Designated Storm, and
- A freeboard allowance, that accounts for uncertainties in the methodology.

Flood Construction Levels (FCL's) are intended to provide safety and security against flooding or related damage in habitable levels of buildings along the shoreline. The extent of flooding or the risk to personnel is directly related to the quantity of water that crosses the shoreline during a storm and for this reason the main focus of this refinement of FCLs has focused on the specific wave effects to be expected at specific locations around the shoreline of the DNS.

Approach and Methodology

The 2011 Provincial Guidelines recommend consideration of 1 m of Sea Level Rise, adjusted for local land movement, for estimating the Designated Flood Level (DFL) for 2100. However, the rate of rise of sea level is now generally expected to occur faster than previously estimated in 2011. To allow for these uncertainties and to aid in both short- and long-term sea level rise response planning, a net rise in sea level of 0.5 m and 1.0 m, independent of any particular year of occurrence, have been used for this assessment.

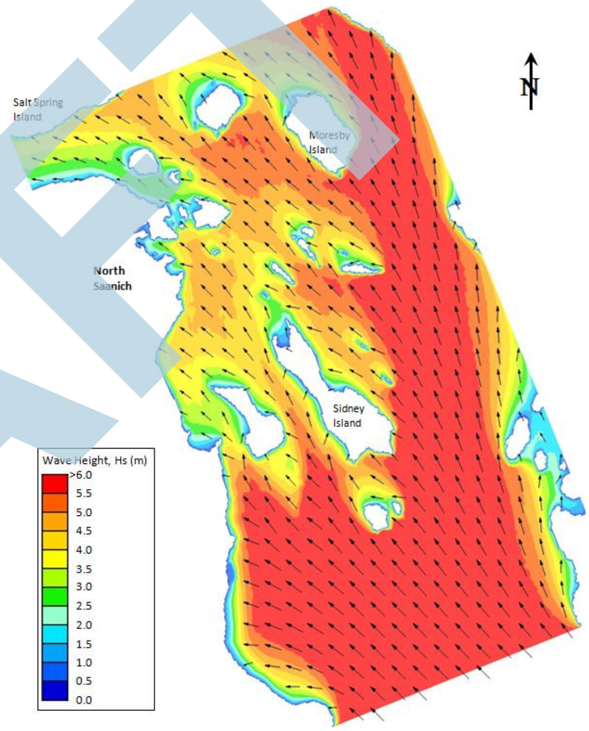
In order to define the Designated Flood Level, an analysis of storm conditions and related water levels was initially undertaken to establish the expected storm surge and associated wind and resulting wave conditions during the Designated Storm for major portion of the DNS shoreline. The Designated Storm was based on a storm that has an average annual probability (AEP) of being equalled or exceeded of 1/500, or a 0.2% chance of occurring or being exceeded in any given year. This level of probability was selected, based on guidance in the Provincial Guideline documents, to minimize and equalize risk to exposed residential properties around the peninsula.

The shoreline of the DNS is exposed to winds and waves from various directions depending on the location, and the type of storm that produces severe (1/500 AEP condition) on that portion of the shoreline. In some cases, depending on the direction of exposure, severe winds (and resulting waves) can come from several different types of storms. The dominant storm patterns include winter outflow conditions that typically produce NE winds, and more typical and relatively frequent, mid-latitude Pacific Ocean storms that generally produce SE, SW, or NW winds.

Detailed analysis found that winter outflow conditions (NE winds) are typically associated with negative storm surges while mid-latitude storms are generally associated with large positive storm surges. It was also found that the peak storm surge generally occurs several hours after the peak wind speed and that the surge can change rapidly as the storm passes over or by the area.

Nearshore wave conditions during the Designated Storm were estimated using a detailed wave generation and propagation numerical wave model (SWAN) for six specific storm scenarios that are capable of producing 1/500 AEP conditions at the shoreline of the DNS. The resulting wave fields vary significantly around the shoreline. The image below shows the expected wave field for a SE storm in Haro Strait.

The DNS shoreline was subdivided into 39 reaches, defined by the typical shoreline characteristics and the wave exposure on each reach. The nearshore wave climate results were then used to establish a governing storm condition for each reach and to then estimate the corresponding wave effects on the shoreline. Wave effects are defined by the wave run-up on the shoreline and/or wave overtopping of shoreline features such as seawalls or rock revetments.



Expected Seastate in a 1/500 AEP SE storm

For the purpose of calculating FCL's, a threshold of 10 L/m/s (Litres/meter/second) for acceptable quantities of water at the shoreline was considered, which provides safety and security of personnel and property. A freeboard allowance of 0.6 m, as recommended in the 2011 Provincial Guidelines, was also included.

Results

The 1m Sea Level Rise scenario resulted in 25 shoreline reaches with FCL's that are lower than the existing uniform CRD estimate of 5.04 m, CGVD28. The remaining 14 reaches have higher FCL's. These changes from the CRD estimate are largely due to the particular characteristics of each reach, including specific shoreline exposure or shoreline characteristics, which includes the type and character of the inter-tidal portion of the shoreline and the nature of the shoreline at the high water line.

The 0.5m SLR scenario resulted in FCL's that are between 0.4m and 1.1m lower than the FCL's for the 1.0m SLR scenario. This reduction is largely due to the lower water level which essentially limits the seastate that can exist at the shoreline during the Designated Storm. For 0.5 m of sea level rise, 30 reaches have FCL's lower than the CRD estimate of 5.04m and 9 reaches have higher FCL's.

The overall reductions in FCL elevations can be largely attributed to the detailed definition of storm scenarios, associated storm surges and the specifics of each shoreline reach. These details are very important when defining specific FCL's on a shoreline as variable as the DNS.

Detailed maps of the resulting FCLs for each shoreline reach are provided in Appendix C.

Implications to the District of North Saanich

There are approximately 713 waterfront lots on the coastline of the District of North Saanich.

For a 0.5m SLR scenario, the revised wave effects and flooding are confined to the shoreline or the first 15 m of setback (Criteria 1 & 2) on approximately 582 lots. Partial flooding, including in some cases, complete inundation (Criteria 3 & 4) is expected on 131 properties.

For the 1.0m SLR scenario, minor flooding (Criteria 1 & 2) is expected on approximately 550 lots. Partial flooding, including in some cases complete inundation (Criteria 3 & 4) is expected on 163 lots.

A potential 77 lots are indirectly exposed to the risk of flooding during a 1.0m SLR scenario, either from an adjacent waterfront property or because flooding may extend landward from the waterfront properties. For a 0.5m SLR scenario, a potential 54 lots are indirectly exposed to flooding. The flooding and safety of these indirectly affected lots is dependent on the action taken on the adjacent lots.

End of Executive Summary

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1. INTRODUCTION

SNC-Lavalin Inc. (SLI) was retained to define the Flood Construction Levels (FCL) for the District of North Saanich, considering district specific conditions such as wave exposure, shoreline type and a range of expected sea level rise scenarios. This report details the methodology and findings of this work and supersedes the previous SLI FCL Report; Document 634533-1000-41ER-001, dated May 2016.

Background

This study refines the Flood Construction Levels (FCLs) previously presented by the Capital Regional District (CRD) In-house Assessment Methodology for the District of North Saanich (DNS). These existing CRD FCLs are described in reports prepared by AECOM [4], CRD [5] and Groundrush Consulting [6].

The existing CRD FCLs were estimated based on the procedures recommended in the 2011 Provincial Guideline documents, BCMOE [1][2][3] and a single value of 5.04 m, CGVD28 was recommended for Zone 4, which includes the DNS. The CRD values were based on a global average sea level rise of 1 m, estimated to occur by the year 2100 [5]. This included a single value of 0.65 m for all areas in the DNS to estimate the Wave Effects component of the FCL. It is expected that the regional application of a single value of wave effects is not accurate, considering the close inter-relationship between the storm surge, wave exposure, Wave Effects, and the varying shoreline types around the DNS shoreline.

Scope

The scope of this assignment was to examine and define the storm surge and wave effect components at a finer resolution than that used for the CRD FCLs and provide revised FCLs specific to the DNS shoreline (shown in Figure 1) for 0.5 m and 1.0 m and of sea level rise.

The following areas were specifically excluded from the study:

- First Nations Lands
- Federal Lands within Patricia Bay (The Institute of Ocean Sciences Marine Facility)
- BC Ferries terminal at Swartz Bay
- Town of Sidney

Vertical Datum

Unless noted otherwise, all elevations are in meters with respect to Geodetic Datum (CGVD28).

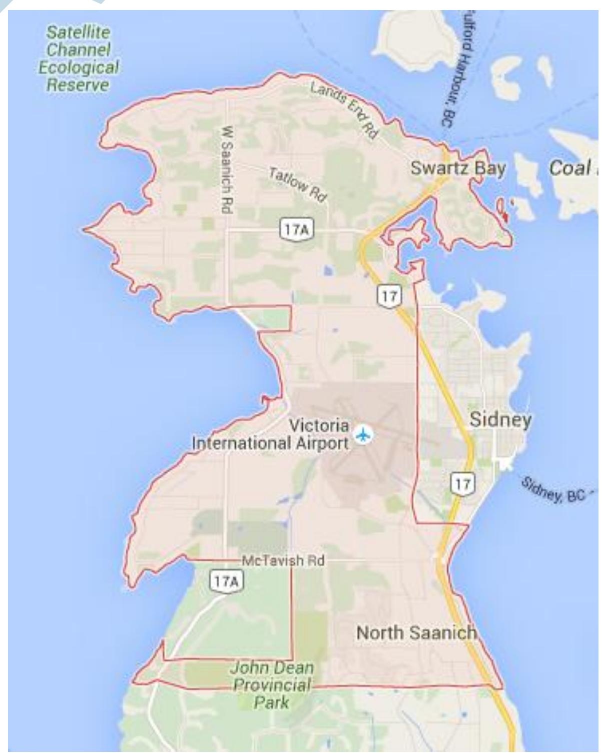

Figure 1: District of North Saanich source: Google Maps 2015

2. METHODOLOGY

In order to estimate the FCL's for the DNS, we used the following methodology, which is consistent with the Provincial Guideline documents and is discussed further in the following sub-sections:

1) Define the Designated Storm(s) and the associated winds and storm surge
2) Determine the Designated Flood Level, considering sea level rise, tide conditions, and storm surge
3) Characterize the incident wave climate approaching the shoreline
4) Determine Wave Effects and overtopping rates at the shoreline
5) Calculate the Flood Construction Levels
6) Determine the number of affected lots in the DNS

2.1. Designated Storms

The Saanich peninsula is exposed to winds and waves from six principle directions; NE, E and SE, SW, W and NW, but in general terms, the east shoreline is only exposed to NE, E and SE, E winds, the west shoreline is only exposed to SW, W and NW winds and the north shoreline is only exposed to NE, N and NW winds. In order to define FCLs around the entire shoreline of the DNS, it is therefore necessary to consider different combinations of wind speed, direction, and related storm surge to determine the governing case for each section of the DNS shoreline.

Definition of the Designated Storm

The 2011 Provincial Guideline Documents provide some flexibility in the choice of the appropriate annual exceedance probability (AEP) for the Designated Storm, based on the type and value of land use along the shoreline. For the purpose of this project, an annual exceedance probability (AEP) for the Designated Storm (DS) of 1/500, which corresponds to a 0.2% chance of occurring in a given year, was selected.

This AEP value was chosen for the following reasons:

- The CRD based results [6] indicated the most vulnerable lands (in the Tsehum Harbour area) were generally high value residential waterfront properties
- Other vulnerable areas on the west side of the peninsula were also mainly residential properties.

Storm Types and Wind Field

Due to the exposure of the DNS to winds and waves from various directions, typical storm patterns that could produce 1/500 AEP winds and waves – i.e.: the Designated Storm – at different locations around the shoreline, could come from two primary sources: winter outflow conditions, which generally produce NE storms or more typical and more frequent mid-latitude storms, from the Pacific Ocean basin, which generally produce SE, SW, and then NW winds, as the storm system propagates towards and across the south coast of British Columbia.

Typical patterns for the storm types are shown in Figure 2. The left hand side shows the typical wind directions around an intense mid-latitude low pressure system as it approaches the coast of British Columbia from the Pacific. This direction of approach initially brings strong E to SE winds that change to SW winds as the associated warm front passes and then often produce strong W to NW winds when the associated cold front crosses the coast. Severe mid-latitude storms typically bring large storm surges, reflecting the effect of the storm, that, within the Straits of Juan de Fuca and Georgia, often occur after the strongest E or SE winds have occurred. The right hand image in Figure 2 shows a typical outflow condition where a ridge of high pressure north of Vancouver Island results in pressure contours that drive strong NE outflow winds across the Strait of Georgia towards Vancouver Island and the DNS.

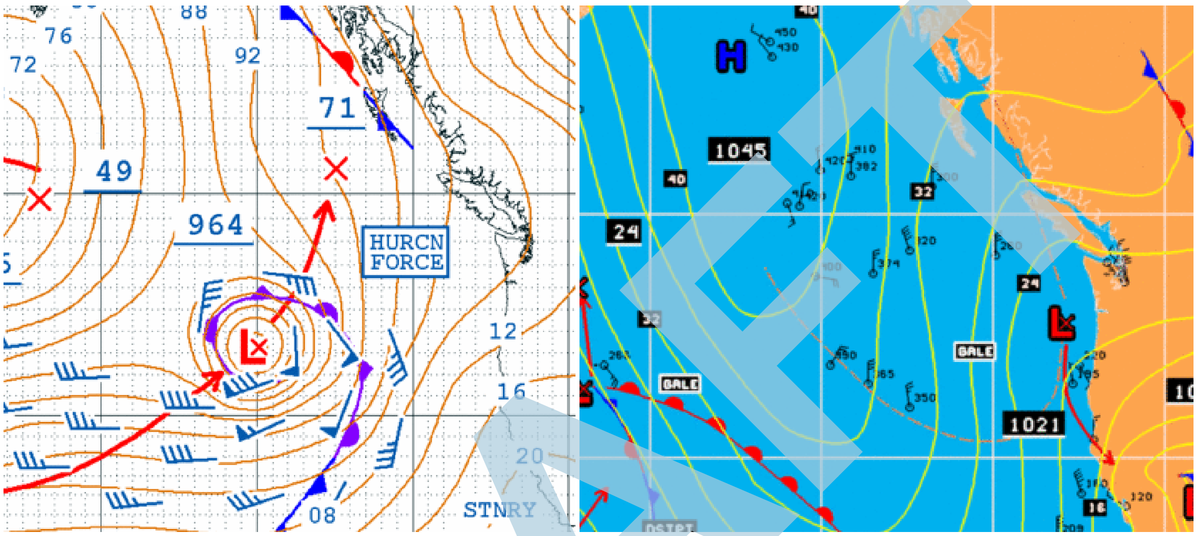

Figure 2: (left) Forecast for a typical mid-latitude storm 17 Jan. 2016 - (right) Forecast for a typical outflow condition 14 Feb 2006
Source: NOAA

Review of the local overwater wind fields in the vicinity of the Saanich peninsula during severe storms also shows that generally during SE storms; the wind speed progressively decreases in strength as the winds approach the Sidney area. Winds in the eastern end of Juan de Fuca strait are consistently stronger than the winds at Kelp Reef, at the north end of Haro Strait. Winds in the area between James Island and Sidney Island and the Sidney shoreline are less than the wind speeds recorded at Kelp Reef.

The expected wind speeds associated with severe storms, and specifically the Designated Storms, (with an AEP of 1/500), were evaluated for this assignment using data from the Environment Canada Victoria Airport anemometer, due to its proximity to most of the DNS shorelines and it's long record, supplemented by data from the Environment Canada anemometer at Kelp Reef, for SE events and from the Environment Canada Wind and Wave recording buoy in Patricia Bay for SW and NW events. Anemometer locations are shown in Figure 3.

Wind speed data from Victoria Airport was adjusted to account its over-land location using standard procedures for overland to overwater modification.

A peak over threshold extreme value analysis was completed to estimate the 1/500 AEP wind events for each directional sector for the modified Victoria Airport winds and the unmodified Kelp Reef winds. The results of the extreme value analysis for the modified Victoria Airport data, by major direction, are provided in Figure 4.

The extreme value analysis results confirmed that peak winds at Kelp Reef are stronger, for the same AEP event, than the modified Victoria Airports winds, which supports the qualitative description of SE overwater wind fields above.

Figure 3: Environment Canada wind stations referenced for DNS project source: Google Earth

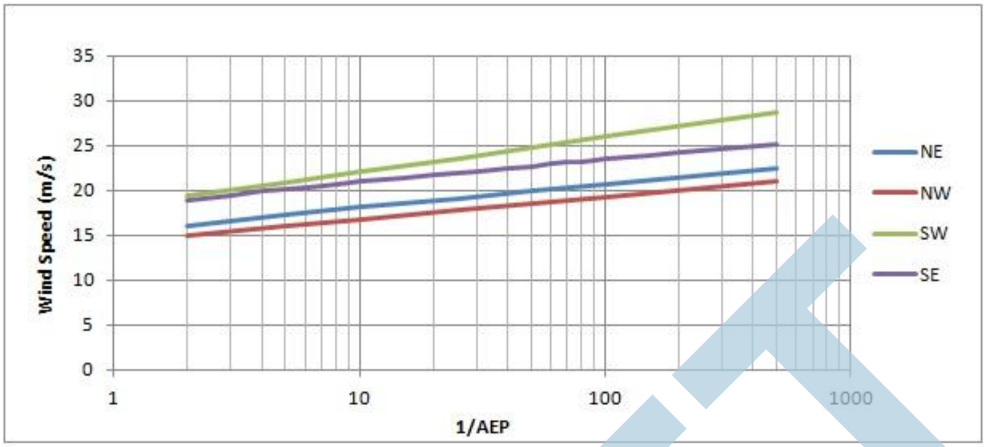

Figure 4: Extreme Value Analysis Results for Wind Speed

Storm Surge during the Designated Storms

In the 2011 Provincial Guidelines, the expected storm surge for a generalized 1/500 AEP storm event in the Strait of Juan de Fuca or the Strait of Georgia is 1.3 m. However, detailed examination of the correlation between the storm surge event and the winds during the related storm event shows that the correlation between the timing of wind speeds in the Straits and the arrival of a storm surge varies significantly. As an example the recorded data shows that the peak wind speed during a recent severe SE storm on the south coast preceded the peak storm surge by approximately 6 hours at Point Atkinson, Figure 5. A similar lag can be expected around the DNS shoreline.

Examination of the top 7 storm surge events in the last 20 years showed that:

- In general, winds during storms tend to peak several hours before the maximum storm surge arrives.
- In most cases, winds have already shifted from a SE to a SW direction and the wind speeds have generally decreased from the peak wind speed.
- In the most severe storm surge event in the record, the winds peaked when the direction had already shifted into the SW.

An examination of the storm surge associated with strong NE or NW winds, which directly affect the north and west sides of the DNS shoreline, shows there are further significantly different correlations between wind strength, as described further below.

It is overly conservative, for the DNS area, to pair the 1/500 AEP storm surge (1.3 m) with a 1/500 yr AEP wind for all Designated Storm direction scenarios.

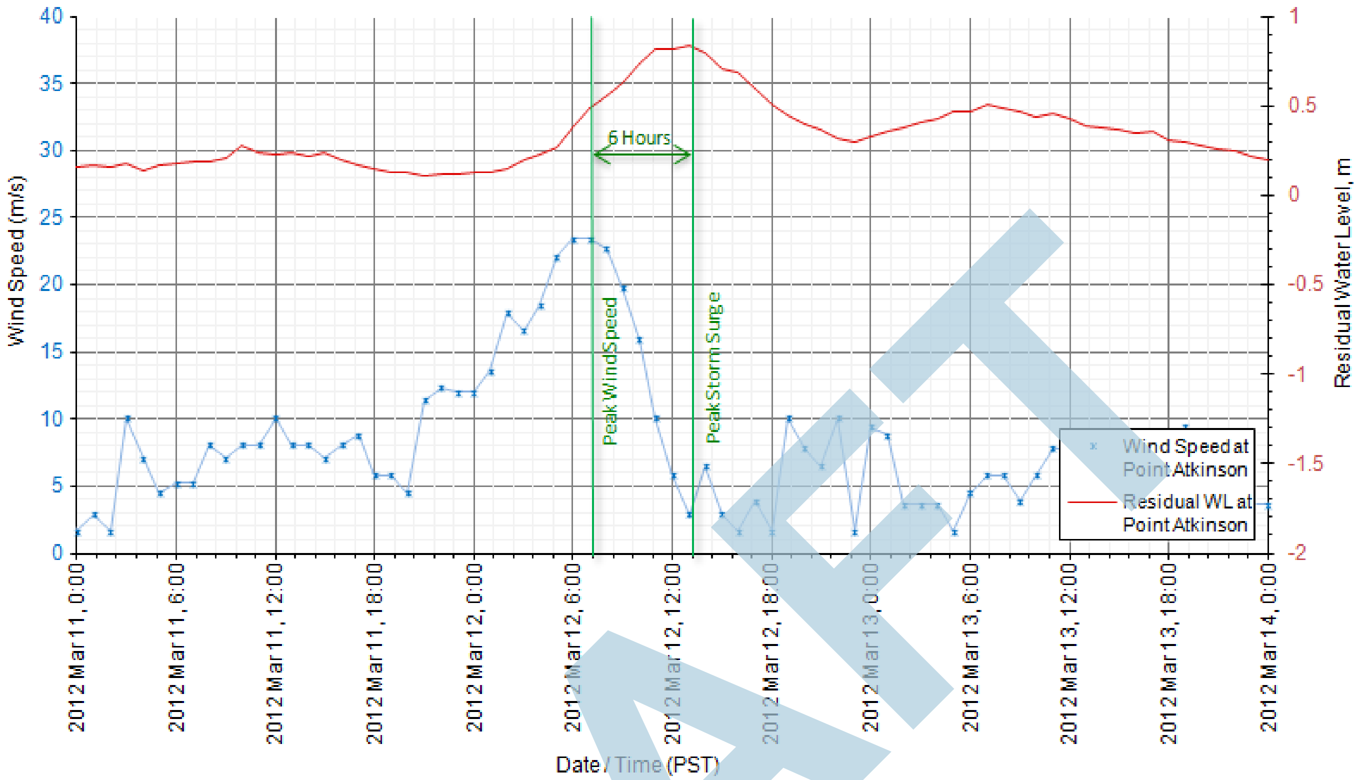

Figure 5: Correlation of Residual water level and wind speed during a SE storm event

For the purpose of this assignment, a specific assessment was conducted correlating wind events with storm surges by directional sector, and specifically for the NE, NW, SW, and SE sectors.

The analysis was based on the top 10 storms on record and a relationship was determined between peak wind speeds in the Sidney area and the corresponding storm surge, for each directional sector. The relationships for the top 10 SE and NE storms in the record are shown in Figure 6 and Figure 7, respectively. The expected wind speed for the Designated Storm is also shown.

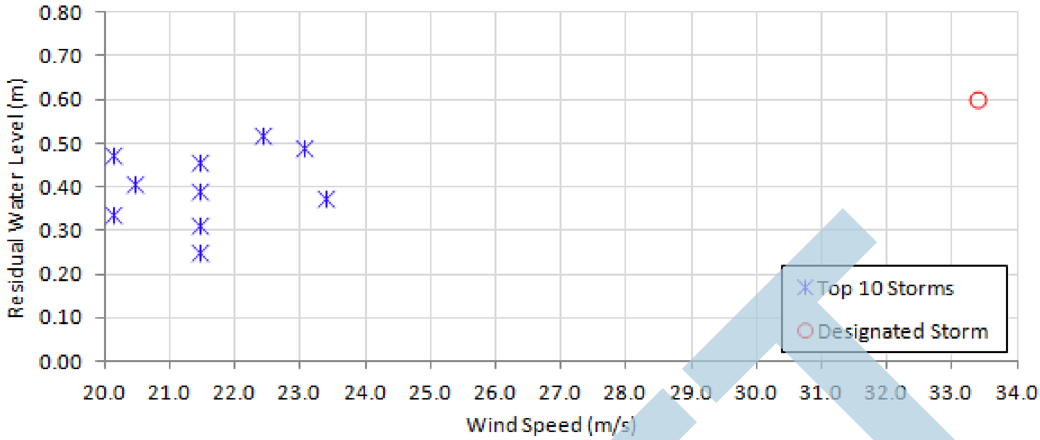

Figure 6: Residual water levels at the time of peak winds for a SE storm.

Source: modified Victoria Airport winds

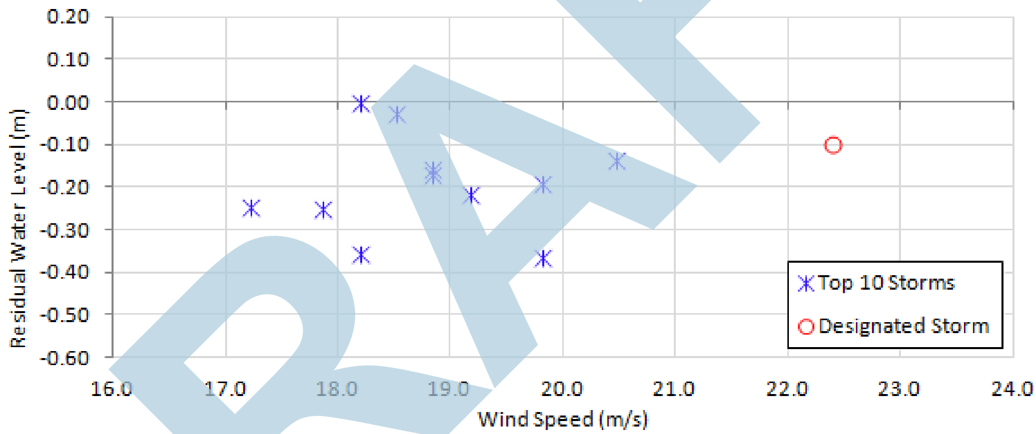

Figure 7: Residual water levels at the time of peak winds for a NE storm event.

Source: modified Victoria Airport winds

The results in Figure 6 suggest that significantly lower storm surge amplitude, compared to the Provincial Guideline of 1.3 m, can be expected when winds actually peak in the waters offshore of Sidney.

Analysis of the top 10 NE storms, Figure 7 suggests that there is a negative storm surge (residual) during severe NE storm events. Analysis of strong NW events provided similar correlations.

Analyses of SW storms showed that the correlation between peak SW winds and residual water levels is similar to that found for the SE storms – the expected storm surge at the time of maximum SW winds is also less than suggested by the Provincial Guideline documents. However, it was noticed that at the time of the largest recorded storm surge on record (0.9 m), winds at Victoria Airport (and Kelp Reef) had swung to the SW.

These results suggest that there is more than one storm scenario that could produce governing storm related Wave Effects around the Saanich peninsula:

- The time at which winds (and related waves) peak and the storm surge is not a maximum
- The time when the storm surge is a maximum but winds (and related waves) have either not yet peaked or they have already started to decrease.

In reality, there are many possible combinations of water levels (astronomical tide plus storm surge) and waves which could produce governing Wave Effects around the peak of the storm for several hours. For the purpose of this assignment we have concentrated on the likely governing scenarios that could define appropriated FCLs.

2.2. Designated Flood Level

The designated flood level (DFL), which does not include the effect of waves at the shoreline, is the sum of the following components [2]:

- Future SLR Allowance
- Maximum high tide (HHWLT)
- Total storm surge during the Designated Storm

The DFL will vary around the shoreline perimeter of the DNS, depending on the exposure of each section of shoreline and the timing of the Designated Storm, winds, storm surge and resulting waves for the particular shoreline exposure.

Sea Level Rise

The existing 2011 Provincial Guideline documents are based on an estimated linear rate of SLR through 2200. The recommended planning curve is shown in Figure 8 as the BC 2011 Planning Curve.

The BC 2011 Planning curve suggests that 1 m of SLR should be expected by the year 2100. However, the weight of science and data related to ongoing sea level rise strongly suggests that 1 m of SLR may occur sooner, as suggested by more recent projections, also shown in Figure 8.

One component of local SLR is the influence of land uplift or subsidence, due either to tectonic effects or glacial isostatic rebound. The current measured land uplift rate in the DNS area is approximately +1.4 mm/yr [1]. This rate, if projected to the year 2100, will result in land uplift of roughly +0.1 m and a slightly slower rate of local SLR than indicated in Figure 8

If the more aggressive SLR projection curves in Figure 8 are representative, then in the most aggressive scenario (the red dashed curve in Figure 8) one meter (1 m) of global SLR may occur by approximately 2065. In this case, the effect of local uplift will be much less and only represents a small fraction of the expected duration until 1 m of local SLR actually occurs.

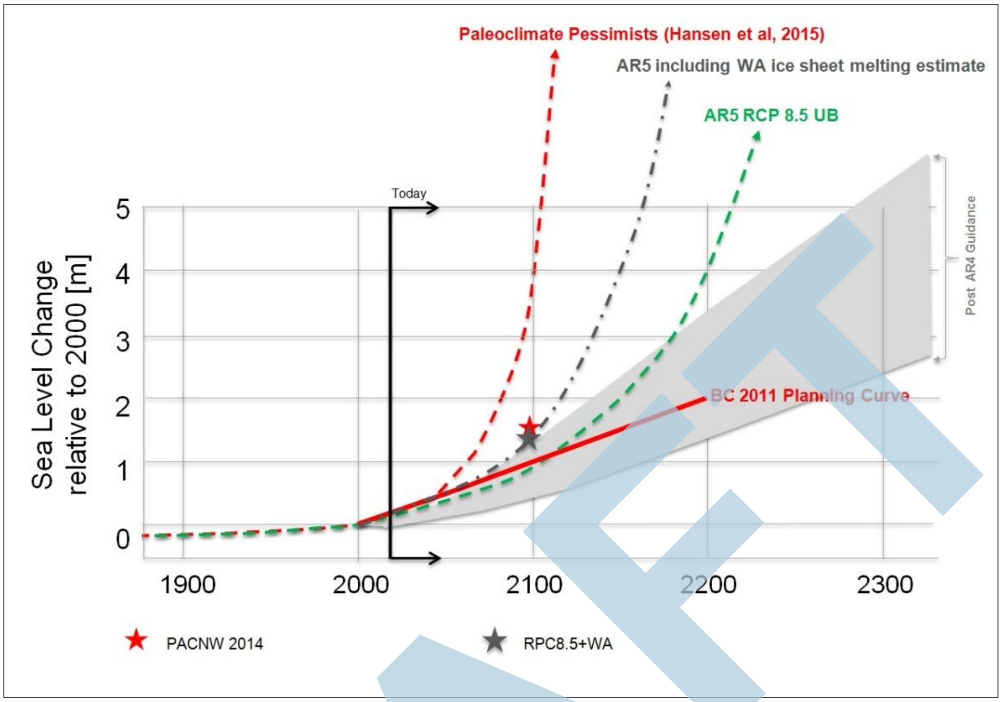

Figure 8: Mean Global Sea Level Rise Projection Curves

For this reason, we have considered two local sea level rise scenarios, 0.5m and 1.0m of net local SLR. These values generally correspond to the estimates for SLR in the year 2050 and 2100 by the 2011 BC Provincial Guideline documents [1], but most likely will occur sooner. The combined interaction of the actual future rate of rise of global sea levels and the appropriate allowance for local land uplift effect is considered to be a part of the inherent uncertainty in the predicted SLR values.

Tidal Water Level

Tide levels vary slightly around the DNS peninsula, with HHWLT ranging from 1.4 m CGVD28 to 1.6 m CGVD28. The specific HHWLT from various local CHS tidal stations are listed in Table 2-1. For the purpose of estimating the DFL, a HHWLT elevation of 1.5m CGVD28, is used.

Table 2-1: Tide Levels at Patricia Bay [8]

Tidal Station	HHWLT (m, CGVD28)
Brentwood Bay	1.6
Patricia Bay	1.4
Swartz Bay	1.5
Sidney	1.4
Saanichton Bay	1.4

2.3. Storm Scenarios during the Designated Storm

The assessment of winds, waves and storm surges undertaken for this assignment has shown there are different scenarios that can affect the various parts of the DNS shoreline depending on the shoreline exposure. In particular, during typical mid-latitude storms, the highest water levels (high tide plus storm surge) may occur after the strongest winds have started to decrease or alternatively after the wind direction has switched, for example from SE to SW. In these cases the incident wave climate and therefore the expected Wave Effects can change significantly and the governing total effect may occur at several moments during the storm that do not exactly coincide with either the time of strongest winds or highest surge.

A summary of the governing conditions is provided in Table 2-2 and Table 2-3 for 0.5 m and 1.0 of SLR, respectively.

Table 2-2: Summary of Designated Flood Levels for 0.5m of SLR

Storm Wind Direction Scenario	Case	Description	SLR Allowance (m)	Tide (m, CGVD28)	Storm Surge (m)	DFL (m, CGVD28)
NE	1	Peak wind	0.5	1.5	-0.1	**1.9**
NW	1	Peak wind	0.5	1.5	-0.1	**1.9**
SW	1	Peak wind	0.5	1.5	0.4	**2.4**
SW	2	Peak surge	0.5	1.5	0.9	**2.9**
SE	1	Peak wind	0.5	1.5	0.6	**2.6**
SE	2	Peak surge	0.5	1.5	1.3	**3.3**

Table 2-3: Summary of Designated Flood Levels for 1m of SLR

Storm Wind Direction Scenario	Case	Description	SLR Allowance (m)	Tide (m, CGVD28)	Storm Surge (m)	DFL (m, CGVD28)
NE	1	Peak wind	1.0	1.5	-0.1	**2.4**
NW	1	Peak wind	1.0	1.5	-0.1	**2.4**
SW	1	Peak wind	1.0	1.5	0.4	**2.9**
SW	2	Peak surge	1.0	1.5	0.9	**3.4**
SE	1	Peak wind	1.0	1.5	0.6	**3.1**
SE	2	Peak surge	1.0	1.5	1.3	**3.8**

2.4. Incident Wave Climate

Definition of Local Wind Climate

Wave generation during a storm is dependent on the wind speed, the related duration, and the extent of open water (fetch) upwind from the shoreline in question.

For the NE, NW, and SW cases, the wind speed and available fetch is almost fully constrained by adjacent land areas and limited open water fetch is available for wave generation. The estimation of incident waves at the shoreline and any resulting wave effects during the Designated Storm is relatively straightforward.

For the NE, NW, and SW-Case 1 scenarios, the 1/500 AEP wind speed based on modified Victoria Airport data, was used. To estimate the incident sea state during a potential 1/500 AEP SW maximum storm surge scenario, a 1/5 AEP wind speed was used for the SW-Case 2 scenario to avoid compounding probabilities unreasonably.

However; for the SE storm scenarios, the incident sea state is initially generated by strong winds blowing across eastern Juan de Fuca Strait from Admiralty Inlet on the US side of the Strait and then further affected by the winds in Haro Strait and then again by the wind in the waters between Haro Strait and the east shoreline of the Saanich peninsula. As the sea state propagates between James Island and Sidney Island in particular, wave dissipation will occur and the dissipated sea state can be re-generated by the decreased winds in this area.

For this assignment, the incident sea states for SE storm scenarios were first estimated in Haro Strait, using a fetch limited assumption across the east end of Juan de Fuca Strait and Haro Strait and then further modified to reflect the influence of Sidney and James Islands and the modification of the wind field in this area. A detailed definition of a wind speed dominated case for the SE direction is beyond the scope of this assignment as it involves estimating overwater wind fields across the entire east of Juan de Fuca Strait during a 1/500 AEP Storm. For this assignment, we have used a conservative scenario of a hurricane force wind speed in the Strait. The estimated 1/500 AEP wind speed, based on modified Victoria Airport data was used for the SE maximum storm surge scenario.

A summary of the wind and offshore wave related parameters for the Designated Storm scenarios is provided in Table 2-4. These scenarios and cases were used to define the expected wave climate at the shoreline, which is further described below.

Table 2-4: Summary of Designated Storm Parameters

Storm Scenario	Case	Description	Wind		Incident Waves		Storm Surge (m)
			Wind Speed (m/s)	Direction (from,°T)	Wave Height, H_s (m)	Period, T_p (s)	
NE	1	Peak wind	22.4	45	-	-	-0.1
NW	1	Peak wind	20.9	320	-	-	-0.1
SW	1	Peak wind	28.6	240	-	-	0.4
SW	2	Peak surge	20.8	240	-	-	0.9
SE	1	Peak wind	33.4	135	5.7	8.4	0.6
SE	2	Peak surge	25.2	135	3.9	7.4	1.3

Definition of the Local Incident Wave Climate

An industry standard wave modeling software, Simulating WAves Nearshore (SWAN) was used to estimate the expected incident wave climate around the shoreline of the Saanich peninsula.

SWAN is a third-generation numerical wave model developed by Delft University of Technology, which computes the generation and propagation of random, short-crested wind-generated waves in coastal regions and inland waters. It is a spectral (phase averaged) model that is valid on mild slopes for the propagation of waves influenced by shoaling, refraction, currents, and wind forcing. Dissipation of waves due to white-capping, bottom friction, and depth-induced breaking is accounted for in the software. For this project we have utilized SWAN version 41.01A.

Bathymetry and Grids

Bathymetry data for the SWAN model was obtained from an in-house bathymetric model of the SW coast of British Columbia, which was then refined near the Saanich peninsula. The existing model has various sources of bathymetric data, including data available from NOAA, for US waters in Juan de Fuca Strait and the Canadian Hydrographic Services (CHS) for Canadian waters. For this assignment, CHS Chart 3441 and Chart 3447 were digitized and used as references for bathymetric data in the vicinity of the DNS shoreline. An image of the refined bathymetric model is shown in Figure 9.

Three different computational SWAN grids were used for the different storm scenarios as shown in Figure 9. Sensitivity runs were completed to determine the grid size needed to appropriately define the wave climate at the -10m contour.

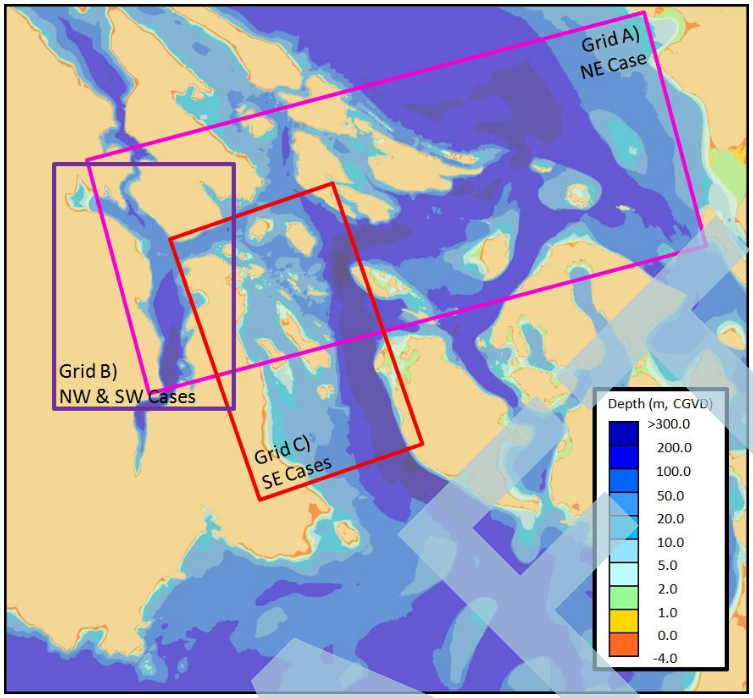

Figure 9: Bathymetric model and SWAN grid extents for designated storm cases

Model Run Scenarios

For the purpose of this project, the six storm scenario cases in Table 2-4 were used to determine the resultant incident wave climate around the Saanich Peninsula.

Whenever possible, it is useful to calibrate numerical wave models with long-term, measured data. The wave buoy in Patricia Bay, which has an approximately 20 year record, was used to calibrate SW and NW winds in order to achieve realistic wave heights during the related model runs. Sensitivity tests were completed to reproduce actual storm events measured at the Patricia Bay Buoy. The tests resulted in the following conclusions:

- SW and NW wind speeds can be reduced to 85% of the modified Victoria Airport wind speeds for numerical modeling purposes to account for the duration-limited wind conditions and stationary modeling methods used for these directions.
- Governing SW winds predominantly occur from 240^{o}, rather than directly down the longer fetch in Saanich Inlet. The shorter 240^{o} fetch results in a more realistic nearshore wave climate in the affected areas.

NE and SE designated storm wind speeds were not reduced, as the Patricia Bay wave buoy is not located in an area indicative of the wind and wave climate on the East side of the Peninsula

A summary of the modeled scenarios and their respective inputs is included in Table 2-5.

Table 2-5: Summary of Model Run Inputs

Storm Scenario	Case	Grid	Winds		Incident Waves at Boundary		Water Level
			Wind Speed (m/s)	Direction (°T from)	H_s (m)	T_p (s)	DFL (m, CGVD)
NE	1	A	22.4	45	-	-	2.4
NW	1	B	17.8	320	-	-	2.4
SW	1	B	24.3	240	-	-	2.9
SW	2	B	17.7	240	-	-	3.4
SE	1	C	33.4	135	5.7	8.4	3.1
SE	2	C	25.2	135	3.9	7.4	3.8

Nearshore Wave Climate

The resulting wave fields for the SW peak wind speed, and SE peak wind speed scenarios, are shown in Figure 10. These images illustrate how the nearshore wave climate can vary significantly along the shoreline for a specific storm scenario. Images showing the resulting wave fields for all storm scenarios are provided in Appendix A.

The nearshore wave characteristics, generally along the -10 m CGVD28 contour, but in some cases, in shallow water areas, along the -5 m or -2 m CGVD28 contour, are shown in Figure 11 for the SW peak wind speed and SE peak wind speed scenarios for 1m of SLR. Summaries of the nearshore sea states along specific reaches of the DNS shoreline, for all scenarios, are provided in Appendix B.

It should be noted these summaries of the nearshore wave climate do not include the potential influence of floating structures (docks or moored vessels) which in some cases, especially near marinas, could attenuate wave energy.

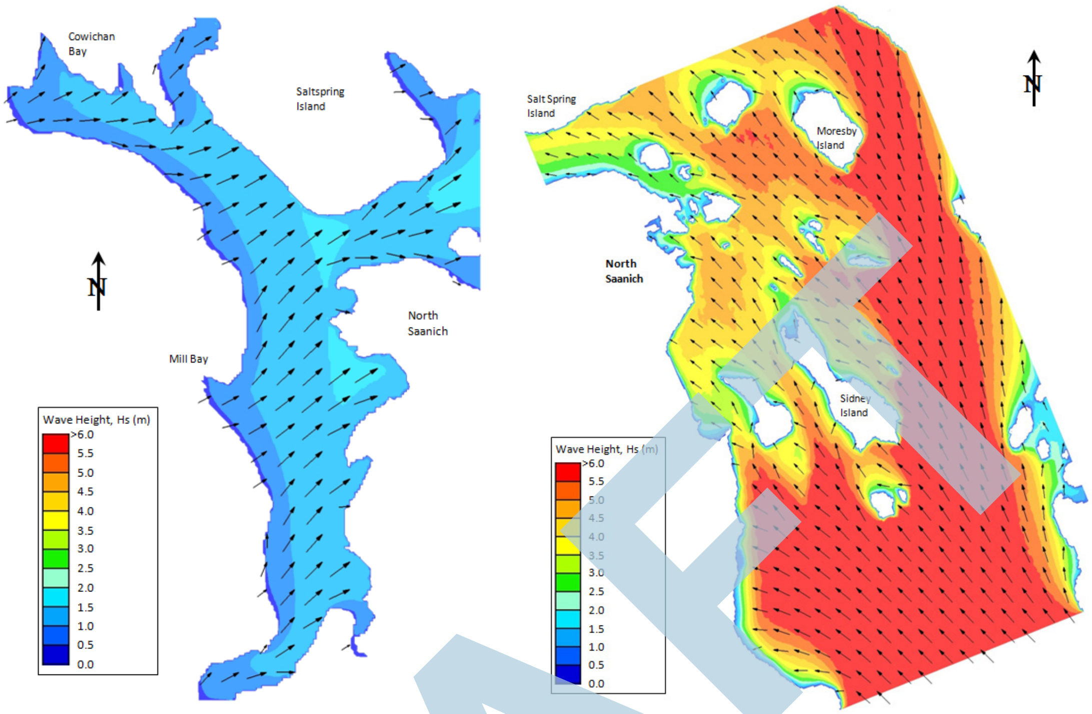

Figure 10: SWAN results for SW peak wind speed (left), and SE peak wind speed (right), 1m SLR

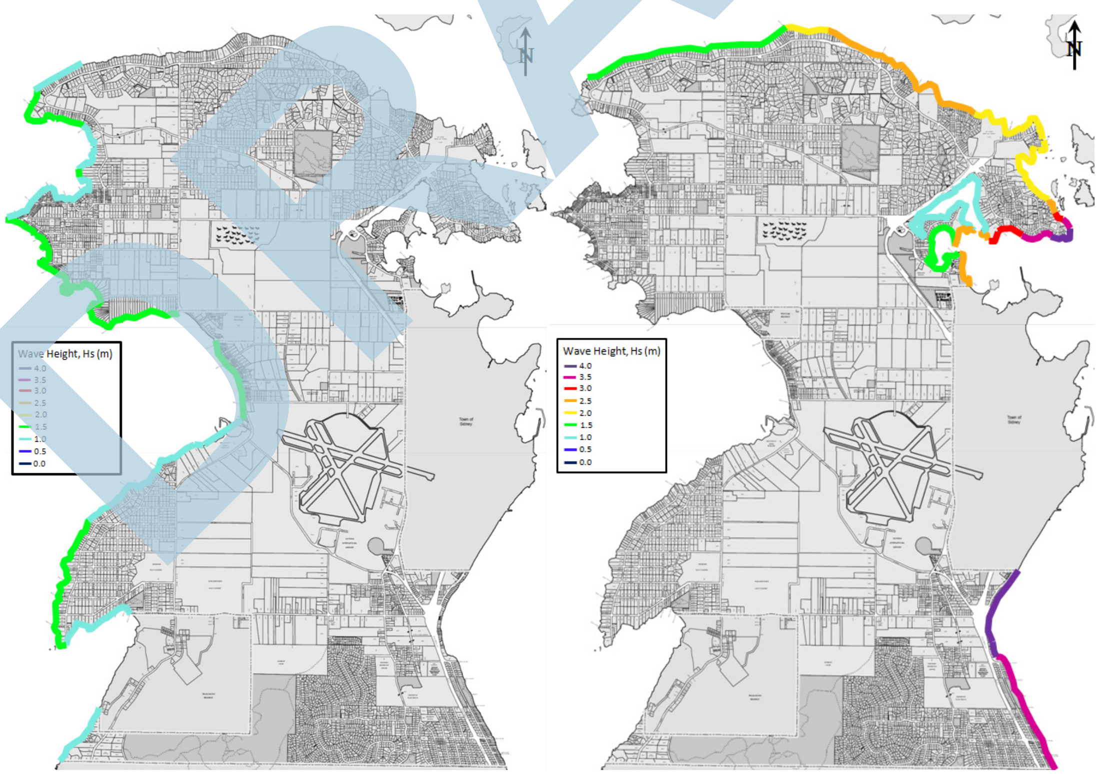

Figure 11: Compiled nearshore seastate, SW peak wind speed (left) and SE peak wind speed (right), 1m SLR

2.5. Wave Effects

The nearshore wave climate results described in Section 2.4 were then used to define the expected Wave Effects around the DNS shoreline for the governing storm scenarios. Wave effects are site and shoreline dependent, and reflect the interaction of the incident waves with a particular shoreline feature. In general terms the Wave Effects will either be wave run-up on the shoreline or wave overtopping of shoreline features such as seawalls or rock revetments. The Wave Effects can result in flooding depending on the elevation of the lands adjacent to the shoreline.

Wave run-up is the vertical distance that water runs up the shoreline/structure slope during the Designated Storm. Wave overtopping is the volume of water that travels over the structure crest and can range from a small amount of spray to a sufficiently large volume capable of damaging structures or flooding of the land. Wave overtopping can be quantified by an average discharge rate, q, in L/m/s (liters/meter of shoreline/second). The average rate of overtopping is essentially defined by the crest elevation of the shoreline structure crest elevation. It should be noted that actual overtopping will occur in individual wave related pulses of water, which, averaged over time, will equal the average discharge rate.

The shoreline types utilized in estimating wave effects are discussed below. A discussion on the appropriate overtopping threshold for defining FCLs is also provided in the following sections.

Shoreline Types

A site visit was conducted by boat on January 14, 2016, to identify the different shoreline types above the high water line around the DNS shoreline. In general, shoreline types range from tall vertical cliffs to mildly sloping beaches. In general, the characteristics of the DNS shoreline can be classified into 3 main types, as illustrated in Figure 12:

- Erodible natural shorelines (green)
- Non-erodible natural shorelines (grey)
- Seawall or revetments (black)

Reaches

The DNS shoreline was divided into 39 reaches, based on the observed shoreline composition and the characteristics of the nearshore wave climate as summarized in Section 2.4. The reaches, alternating in red and blue, are illustrated in Figure 12.

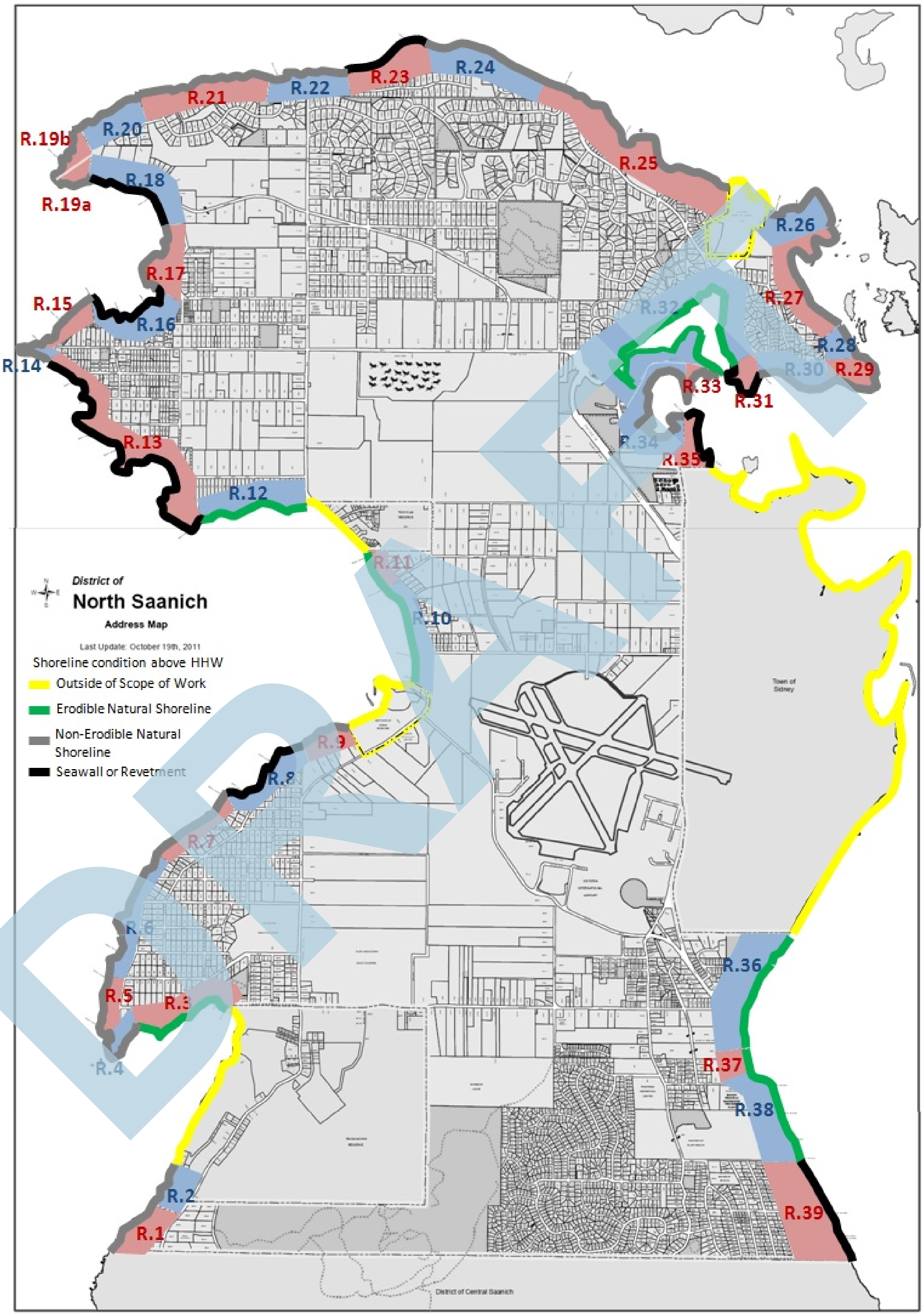

Figure 12: Shoreline Reaches R.1 to R.39

Overtopping Thresholds

In order to determine crest elevations, and therefore FCLs, a threshold for overtopping must be specified. Generally, an overtopping threshold of $q = 10$ L/m/s results in a crest elevation that provides safety and security against flooding to personnel or property behind the shoreline. A threshold of $q = 100$ L/m/s assumes a lower crest elevation and results in more flooding and overtopping. This can mean that it is very dangerous for pedestrians and/or trained staff. This higher threshold also implies wave overtopping that is sufficient to result in damage to any shoreline structures and flooding, with standing water, up to the same elevation as the FCL.

Figure 12 illustrates the level of flooding associated with these two thresholds.

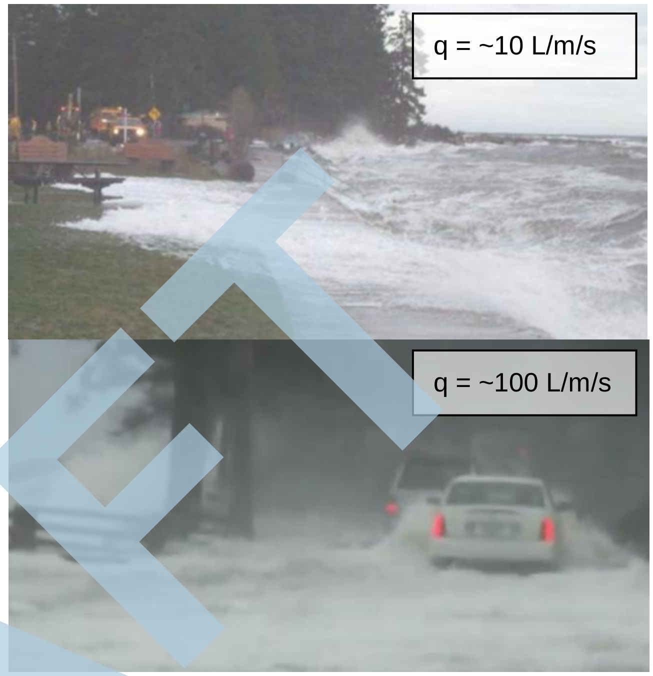

Figure 13: Recent overtopping events in BC corresponding to approximately q = 10 L/m/s (top) and q = 100 L/m/s (bottom)

For the purpose of this study, an overtopping threshold of $q = 10$ L/m/s, was used, which is associated with significantly less risk to people and structures.

Sensitivity tests were also completed using a set of identical nearshore wave conditions to determine the sensitivity of FCL's to the chosen overtopping threshold. The results from these tests are detailed in Appendix D. In Reaches 1 and 32, for example, the overtopping threshold had no effect because wave heights and effects are almost negligible. In highly exposed areas, such as Reach 36, an overtopping rate of 10 L/m/s increases the FCL to 1.5 times the 100 L/m/s FCL; however it implicitly implies a much safer scenario on the related reaches.

Wave Effects

The estimated Wave Effects for each Designated Storm scenario on each shoreline reach for an average overtopping rate (q) of 10 L/m/s were assessed using the industry standard software BREAKWAT, which is capable of assessing all types of shore structure types. BREAKWAT was used to calculate the crest elevation required above the Designated Flood Level (DFL) to limit the average rate of overtopping to the previously mentioned thresholds. The following additional assumptions were made in estimating the Wave Effects:

- The maximum intertidal slope, from the toe of any shoreline feature to the nearshore contour = 1:10
- Wave Effects are based on common shoreline feature for each reach

3. FINDINGS

Flood Construction Levels define either the underside elevation of a wooden floor system for habitable buildings, or the top elevation of a concrete slab for habitable buildings. FCLs should not be interpreted as a required ground elevation surrounding a building intended for human habitation. Other measures, including drainage or wet or dry flood proofing measures may be appropriate where ground levels are lower than the FCL.

Flood Construction Levels were calculated as the sum of the following components for any given reach [2]:

- Designated Flood Level (DFL)
- Estimated Wave Effects during Designated Storm
- Freeboard Allowance

A freeboard allowance of 0.6 m, as recommended in the 2011 Provincial Guidelines is included unless otherwise noted. The factors included in the Freeboard Allowance are discussed further below.

3.1. Revised Flood Construction Levels

The revised FCLs are provided in Figure 15 Figure 14 and Figure 15for a future sea level rise of 0.5m and 1.0m, respectively, for a overtopping rate q = 10 L/m/s. As noted above, the overtopping threshold of q = 10 L/m/s results in an elevation that provides safety and security against flooding to personnel or property behind the shoreline.

At this threshold, 25 reaches have FCL's for a 1.0m Sea Level Rise scenario that are lower than the existing uniform CRD estimate of 5.04 m. The remaining 14 reaches have higher FCL's largely due to the shoreline exposure or shoreline characteristics.

The 0.5m SLR scenario resulted in reaches with FCL's that are between 0.4m and 1.1m lower than the 1.0m SLR scenario FCL's, depending on location. This reduction is largely due to a reduction in water depth which also serves to limit nearshore wave heights. For this scenario, 30 reaches have revised FCL's lower than the CRD estimate and only 9 reaches have higher FCL's.

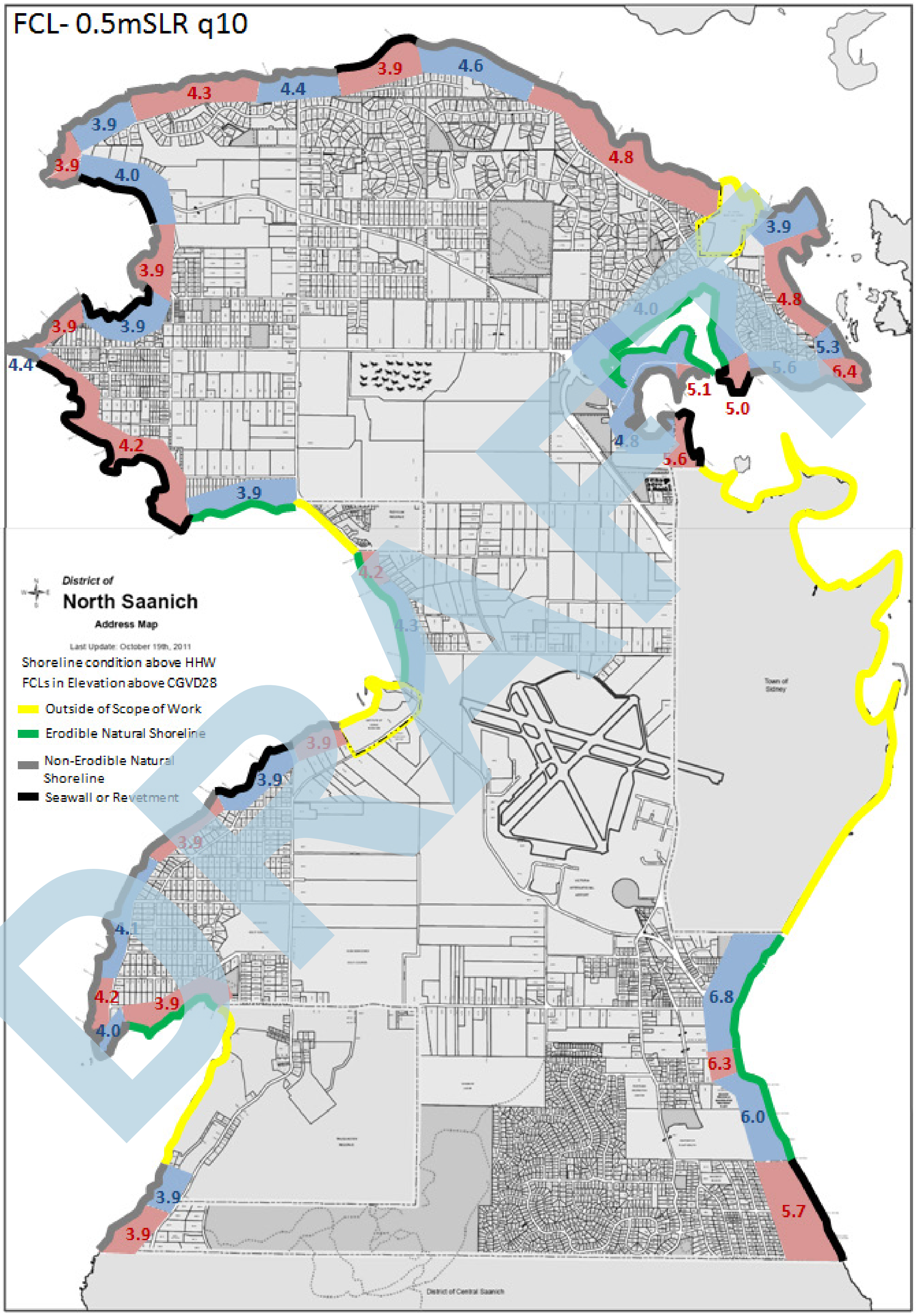

Figure 14: FCL's for 0.5m Sea Level Rise

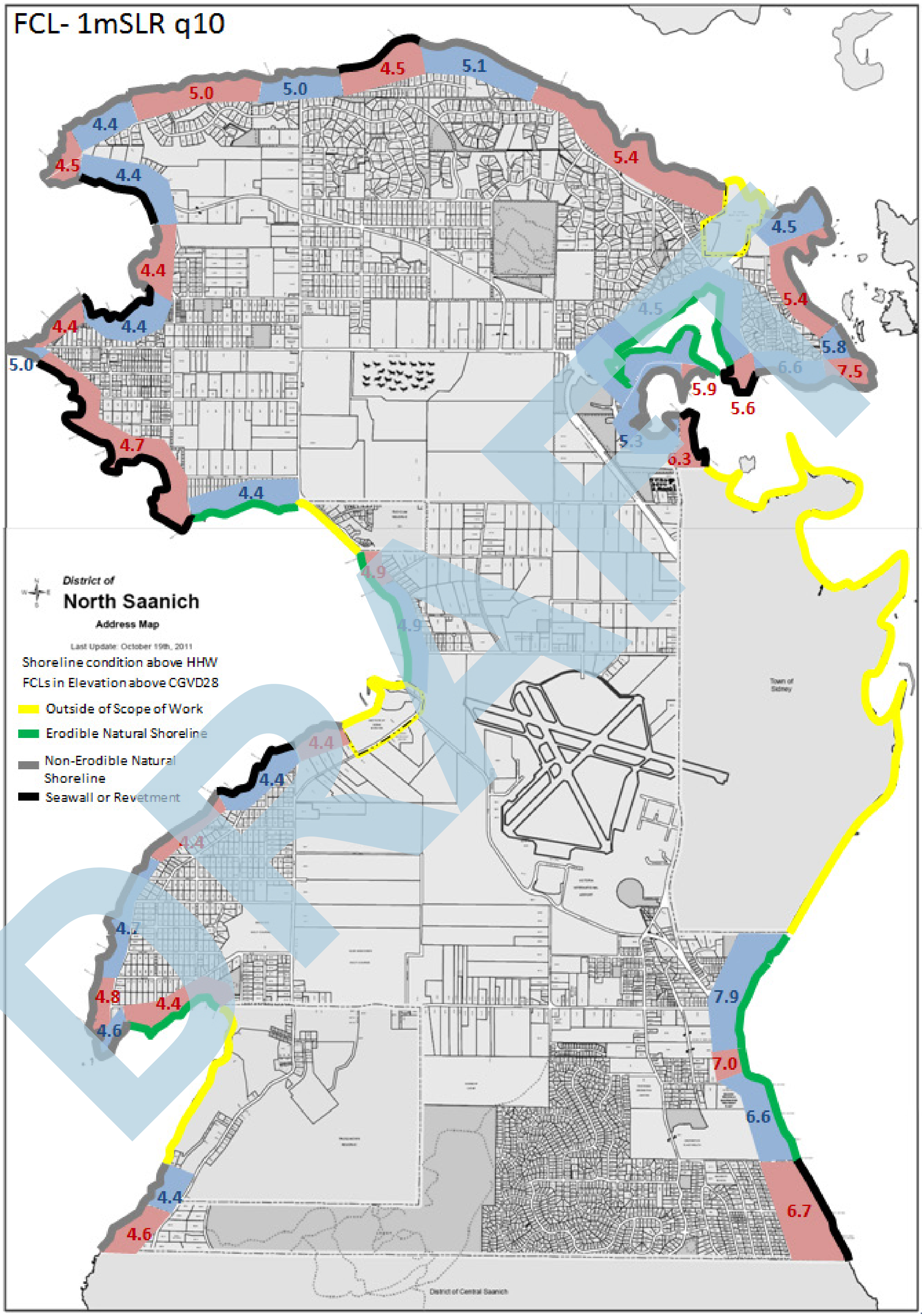

Figure 15: FCL's for 1.0m Sea Level Rise

3.2. Affected Lots

There are approximately 713 properties along the DNS shoreline that are exposed to the future threat of sea level rise and the associated wave related effects. For the purpose of understanding how these lots are affected by the FCL's, we have used the following criteria:

Directly Affected:

1) Lot is not affected: The FCL elevation does not encroach into the lot.
2) Lot is partially affected: The FCL elevation encroaches less than a 15m setback on the lot.
3) Lot is partially flooded: The FCL encroaches beyond a 15m setback, but does not inundate the entire lot.
4) Lot is completely inundated: The FCL elevation encroaches on the entire lot and possibly further landward.

Indirectly Affected:

5) Lot is adjacent to a lot where flooding is expected, which is substantially greater than the flooding for the reference lot.
6) Lot is adjacent to a completely inundated lot.

The levels of inundation were defined using a digital elevation model (DEM) of the District of North Saanich based on LiDAR measurements of District topography. The DEM was provided by the DNS. Lot boundaries are based on Cadastral mapping also provided by the DNS.

Criteria 1 implies that the FCL will have little to no effect on applicable lots and mainly occurs where the shoreline is steep and high.

Lots where Criteria 2 is applicable will have limited flooding or wave interaction, provided that the main building is landward of a 15m setback. Lots affected by Criteria 3 and 4, may require protection or other measures.

Indirectly affected lots are dependent on the action of the adjacent lots. For example, if a waterfront lot constructs a sea wall, the adjacent lots may be impacted by overtopping.

The number of lots affected by 1m and 0.5m FCL's for an overtopping threshold of 10 L/m/s are summarized in Table 3-1. These values are based on the map of the revised FCL's for the entire Peninsula, included in Appendix C.

It is important to note that the total number of directly affected lots is equal to the total number of waterfront lots in the DNS. For the purpose of this analysis, waterfront lots are defined as properties directly adjoined to the ocean, not including parks or areas out of the Scope of Work as defined in Section 1. We also assumed that for properties affected by more than one FCL, the higher FCL governs.

The indirectly affected lots includes lots already counted as directly affected and lots that are typically inland (generally across a road right of way) of a waterfront lot.

Table 3-1: Summary of lots affected by the revised FCL's

Criteria	Number of Lots	
	0.5m SLR	1.0m SLR
Directly Affected Lots		
Criteria 1	83	48
Criteria 2	499	502
Criteria 3	67	81
Criteria 4	64	82
Total	**713**	**713**
Indirectly Affected Lots		
Criteria 5	17	31
Criteria 6	37	46
Total	**54**	**77**

3.3. Uncertainties

As discussed previously, a freeboard allowance of 0.6 m was included in the FCL's to account for uncertainties, which include the following:

- A uniform 1:10 intertidal slope was used based on observations during the field reconnaissance. Steeper slopes could increase the Wave Effects.
- Although the shoreline is sub-divided into 39 reaches, variation in shoreline type, slope, and orientation still exist within each reach. Some of these variations could result in either higher or lower Wave Effects within each reach.
- Nearshore wave heights and wave effects do not consider the effects of local structures, vessels, or docks.
- The numerical wave model computational grid has 100m grid spacing, which is appropriate when considering a 1-2km reach length, but fails to capture some local complexities, such as rapid changes in bathymetry, narrow channels, or small islands, which may be important for an individual lot assessment.
- Shoreline orientations are averaged over the entire reach and within a reach, some lots may be more exposed or less exposed to the Designated Storms.
- Some reaches may be more exposed to waves generated by another wind direction, other than that considered by the Designated Storms. This is an inherent uncertainty of completing FCL's on a highly variable shoreline at a scale larger than that of the individual lot. However, these risks have been appropriately balanced by using some conservative engineering approaches, such as a lower overtopping threshold of q = 10 L/m/s, and by applying a 0.6m freeboard.

- The refined FCL's are largely based on modifications of the recorded overland wind measurements from Victoria Airport and calibration with the Patricia Bay Buoy wind and wave data for SW and NW winds. Ideally, overwater wind measurements would also be available on the East side of the peninsula to validate the modifications made in this study for SE and NE winds.
- The Wave Effects are largely based on the wind climate from the last 60 years of measurements made at Victoria Airport. Climate change is expected to increase the frequency of severe weather events and possibly the intensity of these same events.
- There is a significant variation in present estimates of the future rate of SLR. The flow of new information and science related to future rates of SLR consistently indicates that SLR will occur faster than indicated by the 2011 Provincial Planning Curve. There is no scientific information that suggests rates will be lower. The freeboard allowance of 0.6 m provides an allowance for this particular uncertainly, the magnitude of which also depends on the magnitude of other relevant uncertainties in the calculations.

4. GLOSSARY AND ABBREVIATIONS

Definitions and abbreviations of terms used in this report are listed below.

	2011 Provincial Guidelines	Guidelines posted by BCMOE, BCMOE (2011a,b,c), and available online at: http://www.env.gov.bc.ca/wsd/public_safety/flood/fhm-2012/draw_report.html#3
AEP	Annual Exceedance Probability	The probability of a specific event occurring (or being exceeded) in any given year.
CD	Chart Datum	At the DNS, CD is 2.3m below Geodetic Datum (CGVD28).
DFL	Designated Flood Level	A water surface elevation which includes appropriate allowances for future SLR, land crustal movement, tide, and storm surge during the Designated storm.
DS	Designated Storm	A storm which includes concurrent time series of winds, storm surge and waves, with a specific AEP.
	Fetch	The horizontal distance over open water (in the direction of the wind) over which wind generates waves.
FCL	Flood Construction Level	Defined as the underside elevation of a wooden floor system for habitable buildings, or the top elevation of a concrete slab for habitable buildings [2].
	Freeboard	A vertical allowance added to the DFL and the Wave Effect allowance to establish the FCL. This allowance is generally included to cover any uncertainties in defining the FCL.
HHWLT	Higher High Water Large Tide	The average of the annual highest tides over the 18.6 year tidal cycle.
	Overtopping	The passage of water over the seaward shoreline as a result of wave run-up.
	Residual Water Level	The component of the measured water level that is not attributed to tidal effects. The residual water level is generally assumed to be approximately equal to the storm surge. Calculated as the measured total water level minus the predicted tides at a given location.
	Run-Up	The vertical distance exceeded by 2% of waves that travel up the shoreline/slope during the Designated Storm.
SLR	Sea Level Rise	The rise in sea level including: global sea level rise driven by global warming and local sea level rise driven by regional tectonic or isostatic (glacial) subsidence or uplift.
	Storm Surge	The non-tidal rise/fall in a body of water due to atmospheric effects.

SWAN	Simulating WAves Nearshore	A wave modelling software, which can simulate waves generation and offshore wave transformations to the nearshore.
°T	Degrees, True North	Direction in degrees, with respect to True North.

5. REFERENCES

5.1. Reference Documents

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5.2. General References

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[17] NWS/NCEP Ocean Prediction Center – 48-Hour Surface Prediction

[18] SWAN modeling software - version 41.01A

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6. NOTICE TO READERS

This document contains the expression of the professional opinion of SNC-Lavalin Inc. ("SLI") as to the matters set out herein, using its professional judgment and reasonable care. It is to be read in the context of the Agreement, and the methodology, procedures and techniques used, SLI's assumptions, and the circumstances and constrains under which its mandate was performed. This document is written solely for the purpose stated in the Agreement, and for the sole and exclusive benefit of the Client, whose remedies are limited to those set out in the Agreement. This document is meant to be read as a whole, and sections or parts thereof should thus not be read or relied upon out of context.

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7. REVISION INDEX AND SIGNATURES

Document No.: 634533-3000-41ER-0001

Issue Code	Rev. No	Date (yyyy-mm-dd)	Description of Changes	Initials
RR	PA	2016-09-19	Released for Internal Review	JW
RR	PB	2016-09-21	Released for Client Information and Comment	JSR
RR	PC	2017-01-04	Comments Incorporated	JSR

Issue Codes:

RC Released for Construction
RD Released for Design
RF Released for Fabrication
RI Released for Information
RP Released for Purchase
RQ Released for Quotation
RR Released for Review and Comments

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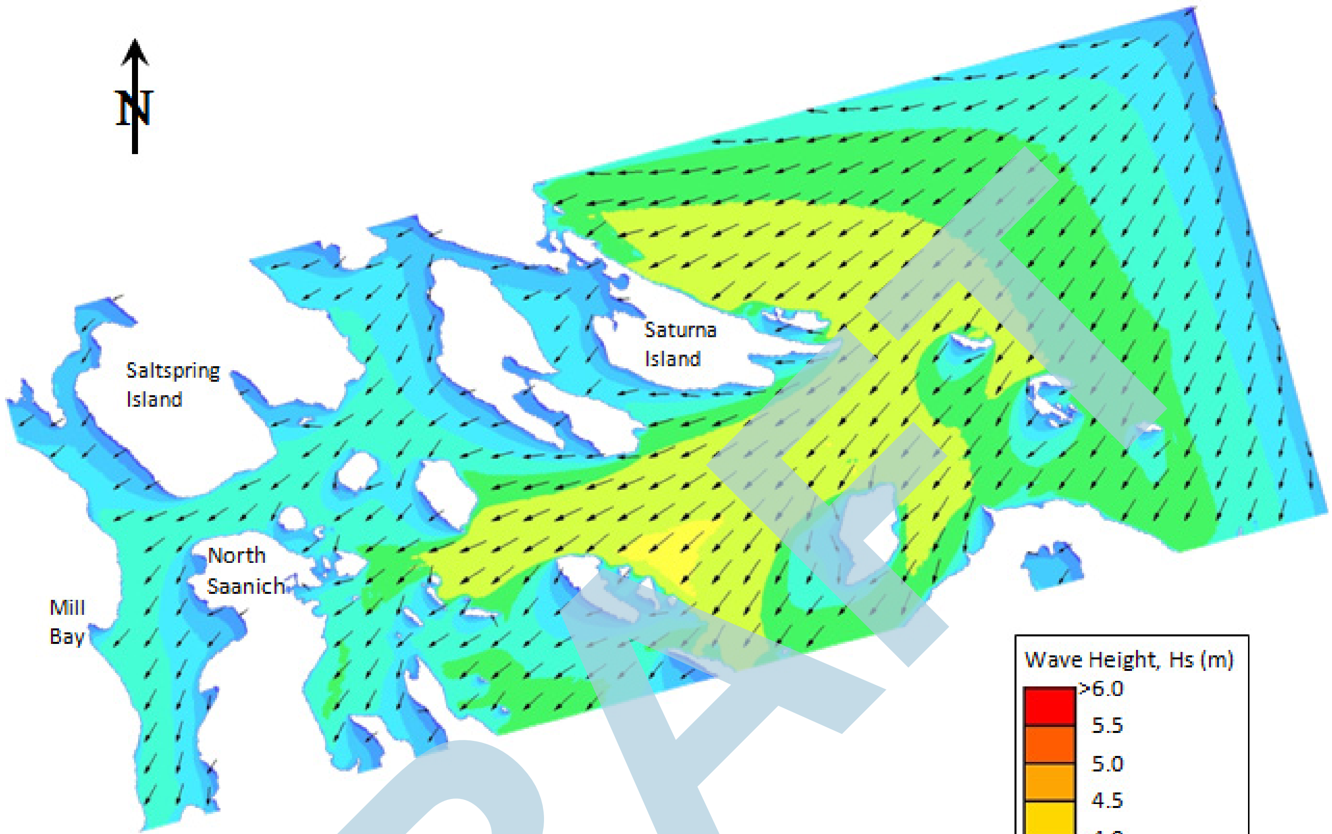
APPENDIX A – SWAN Results



Note:

Wave field valid on a regional scale only.

Not valid for lot by lot assessment.

Figure 1: SWAN results for the NE peak wind speed scenario for 0.5m SLR

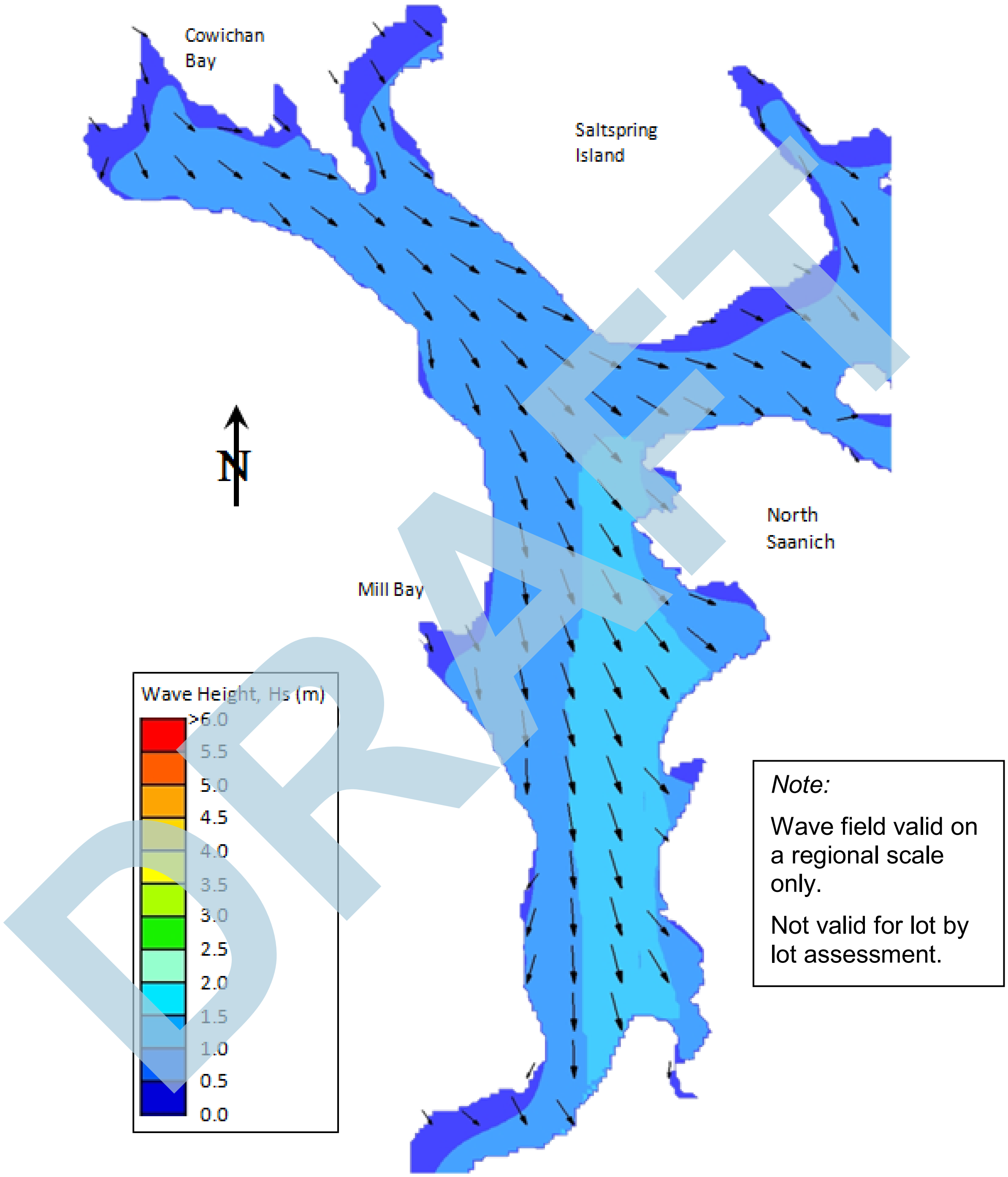


Figure 2: SWAN results for SWAN for the NW peak wind speed scenario for 0.5m SLR

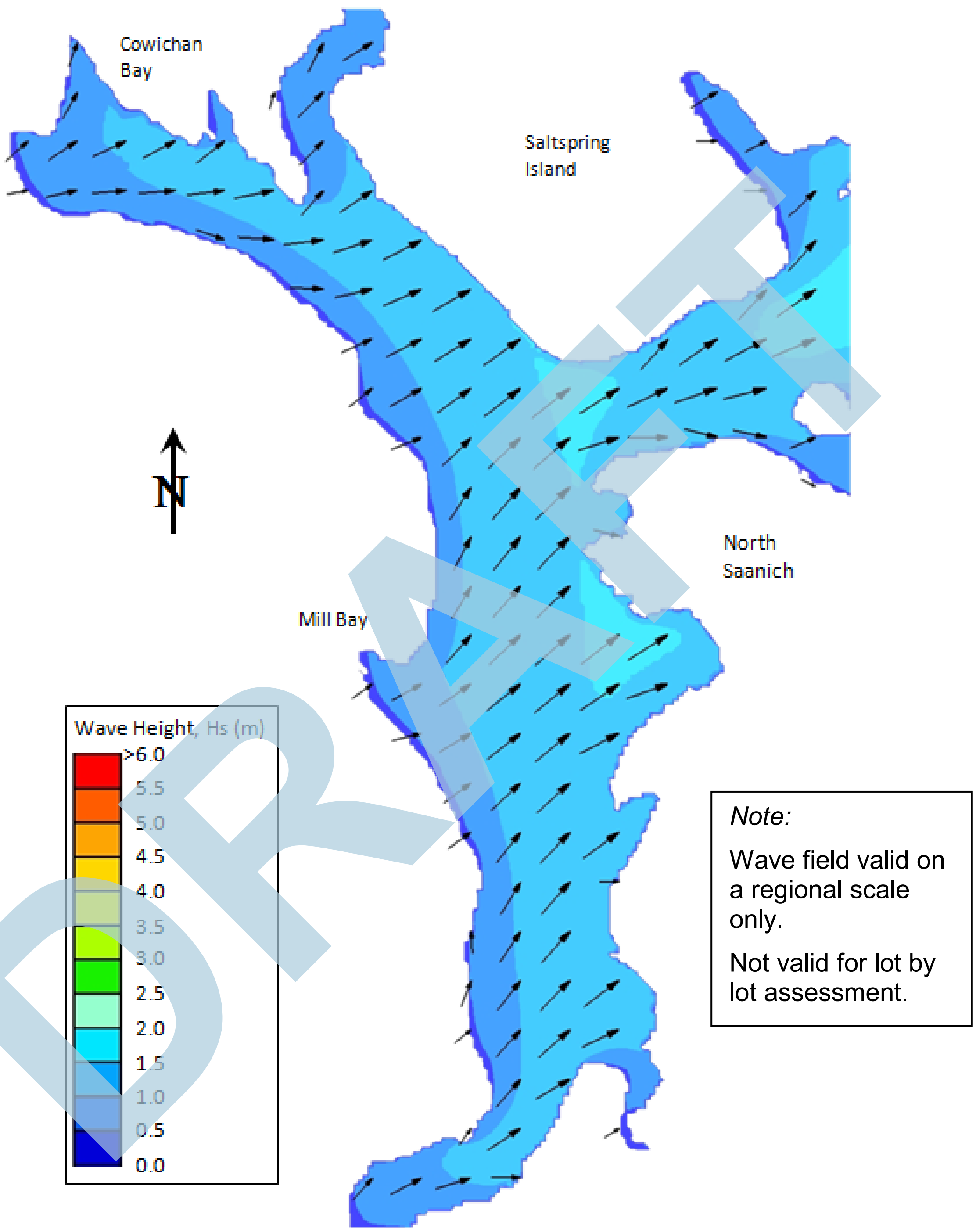


Figure 3: SWAN results for SWAN for the SW peak wind speed scenario for 0.5m SLR

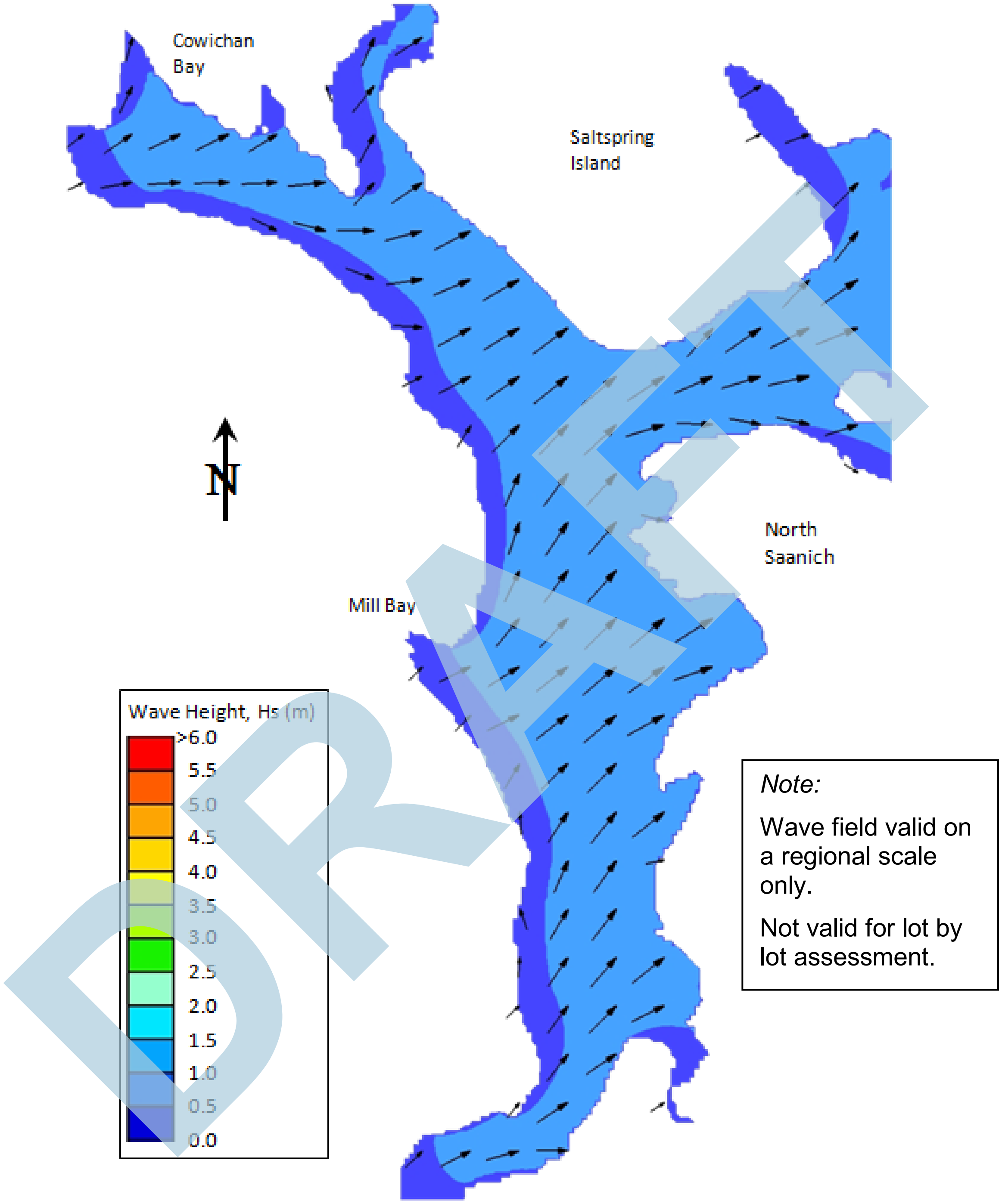


Figure 4: SWAN results for SWAN for the SW peak storm surge scenario for 0.5m SLR

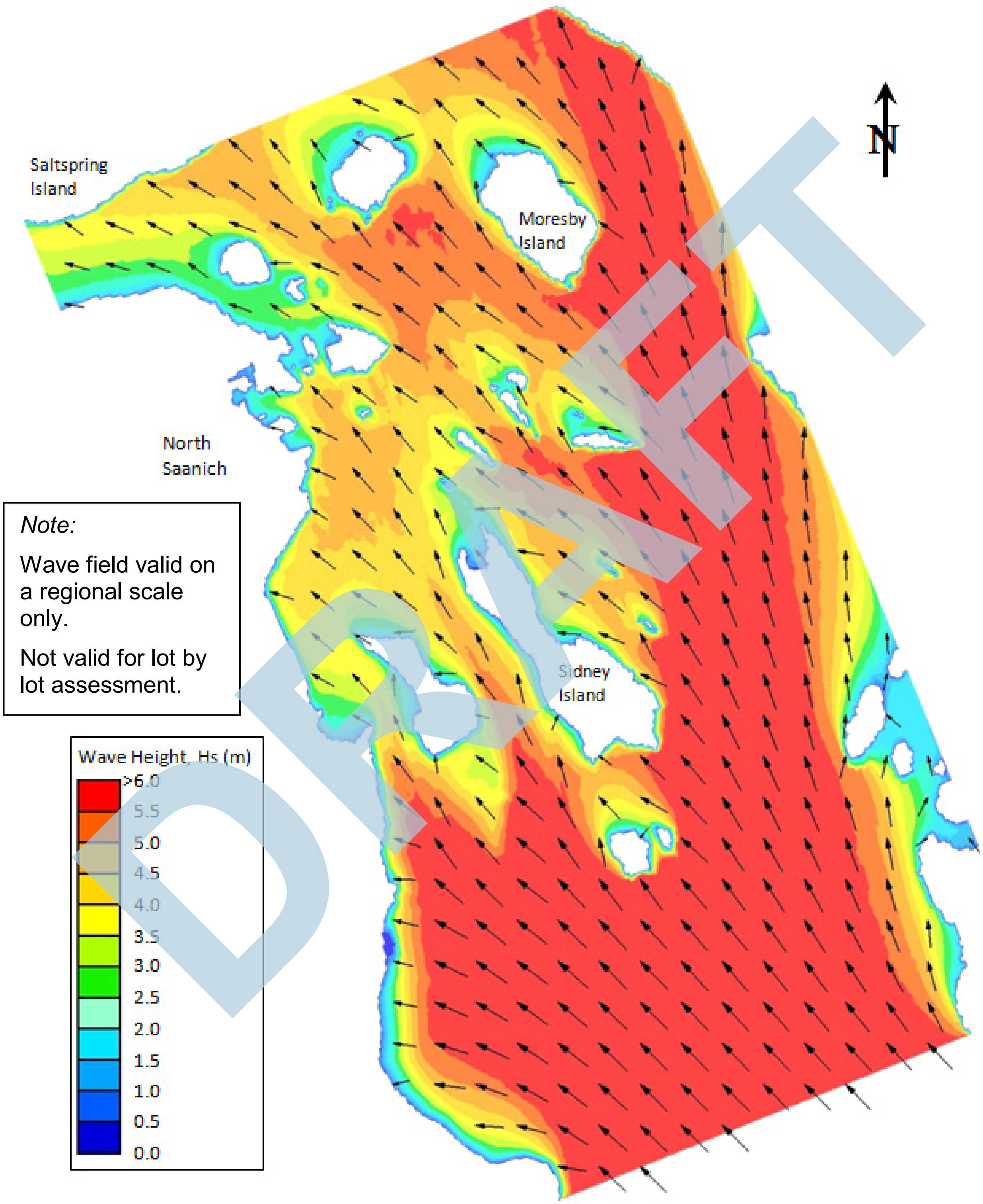


Figure 5: SWAN results for SWAN for the SE peak wind speed scenario for 0.5m SLR

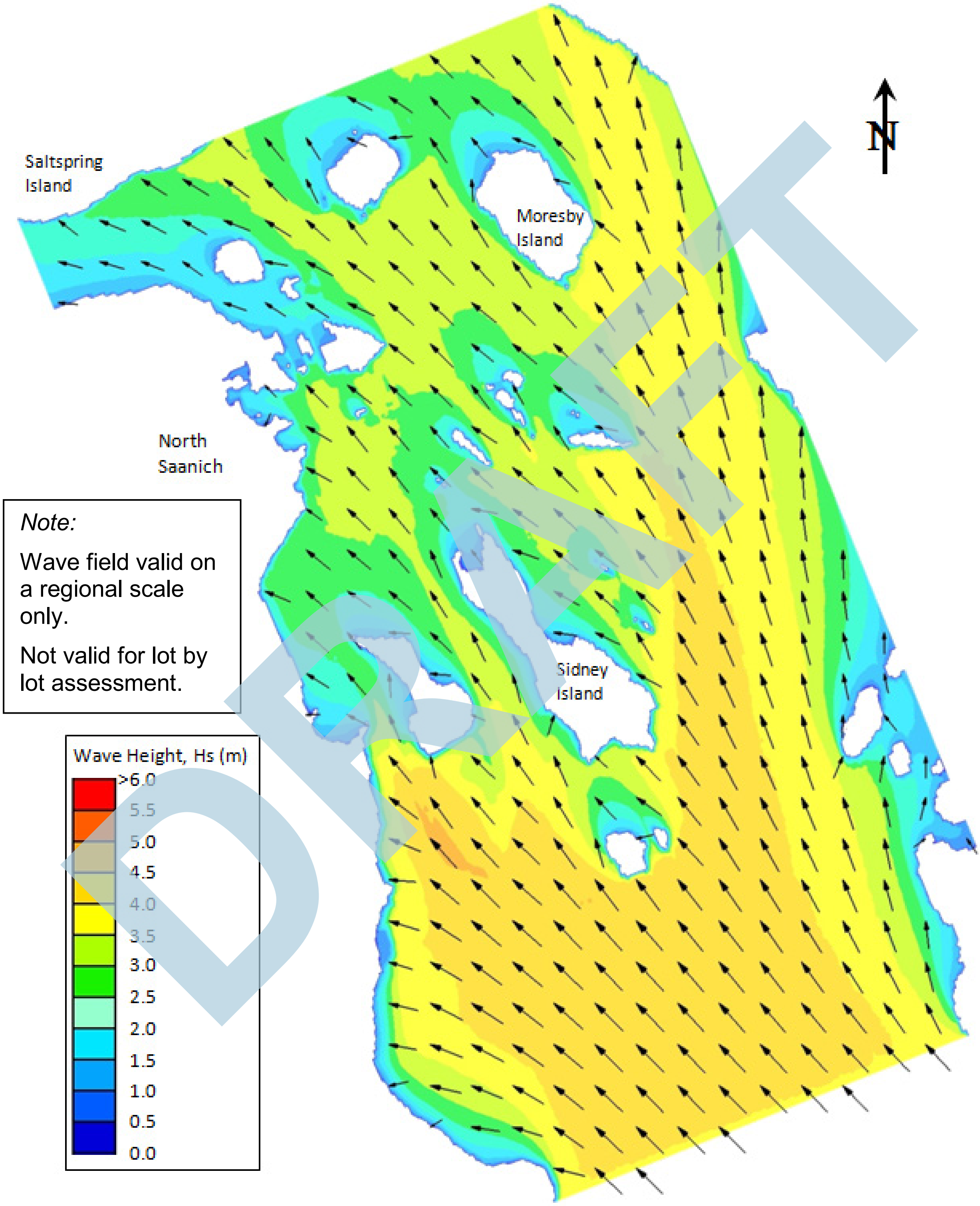


Figure 6: SWAN results for the SE peak storm surge scenario for 0.5m SLR

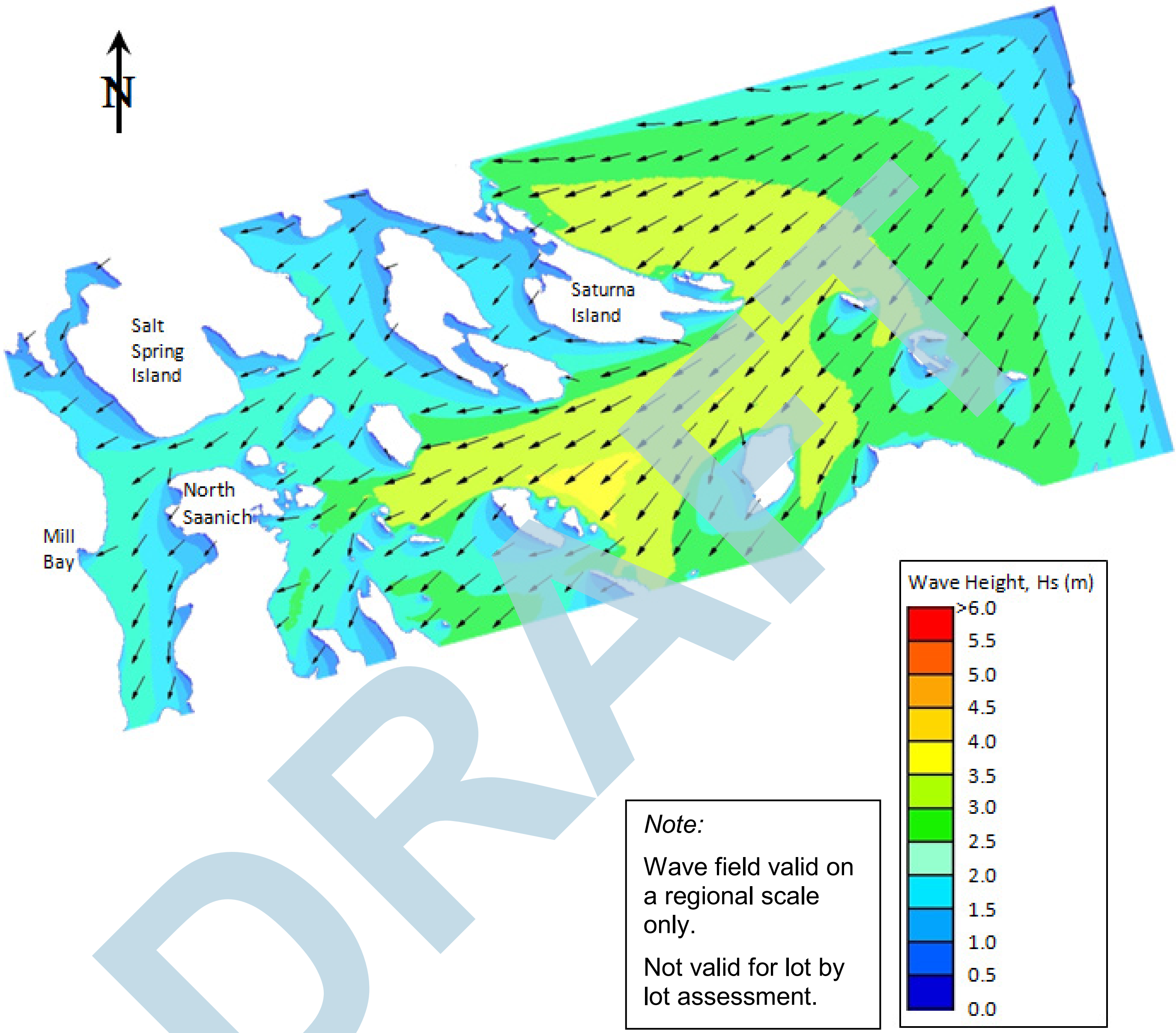


Figure 7: SWAN results for the NE peak wind speed scenario for 1m SLR

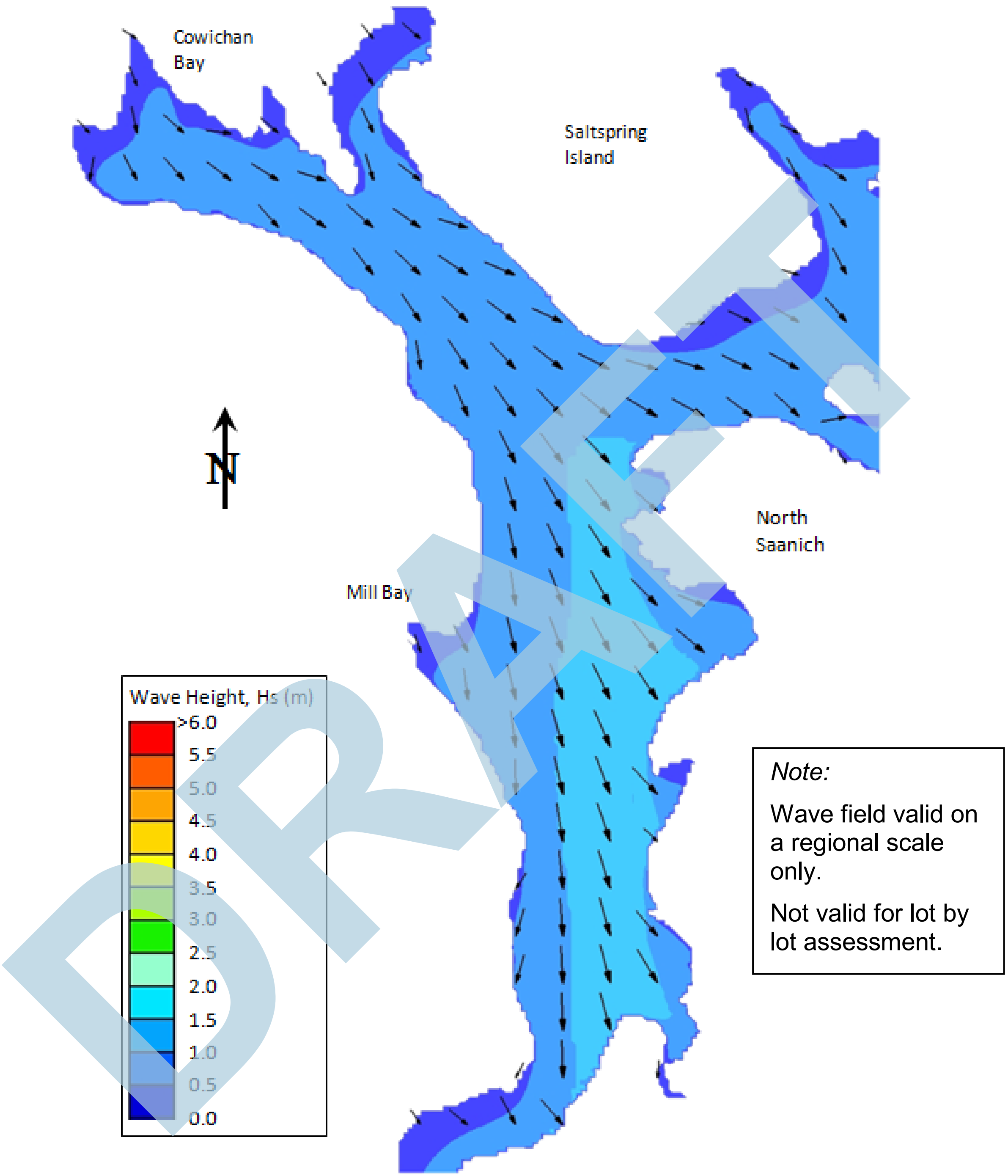


Figure 8: SWAN results for SWAN for the NW peak wind speed scenario for 1m SLR

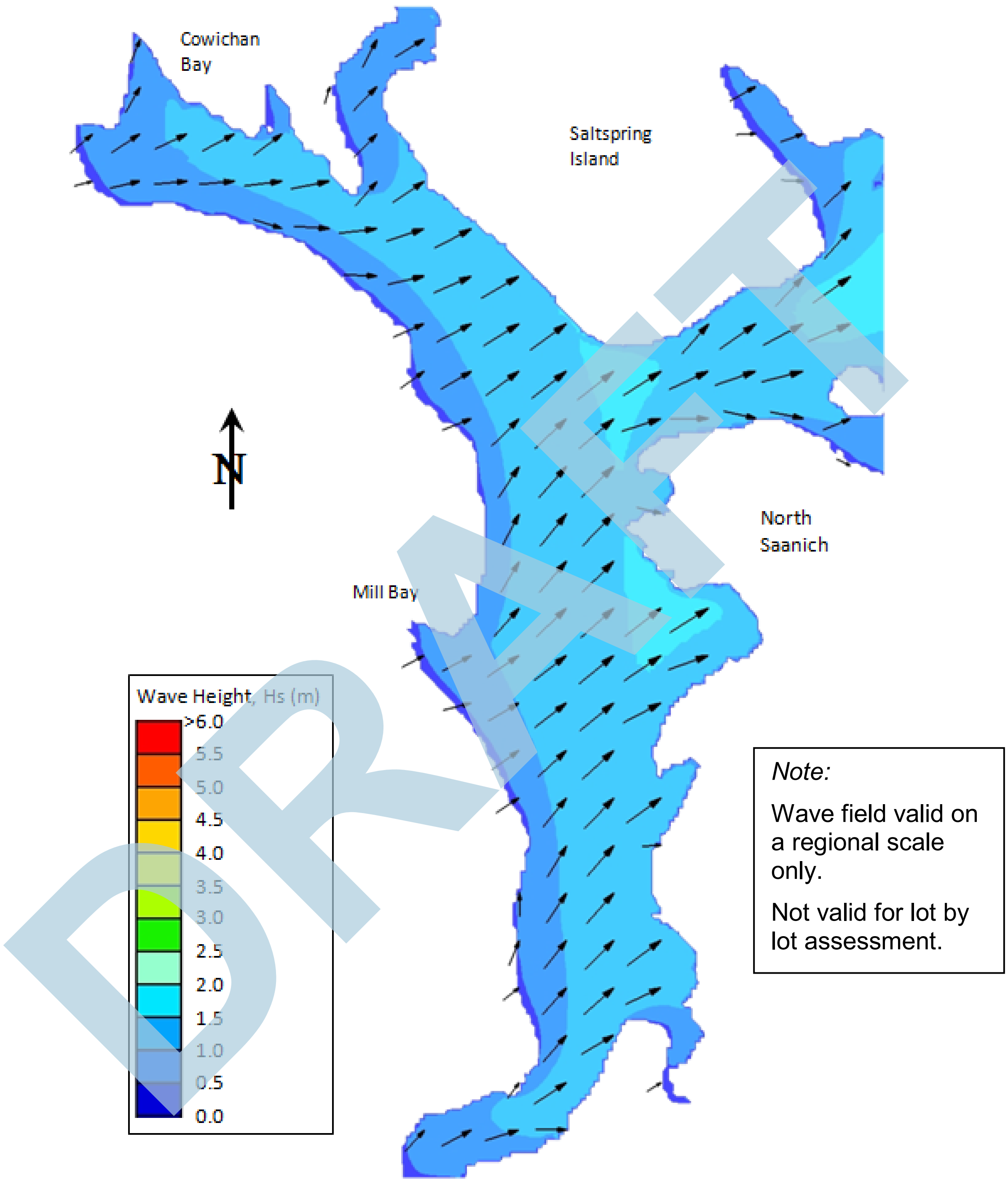


Figure 9: SWAN results for SWAN for the SW peak wind speed scenario for 1m SLR

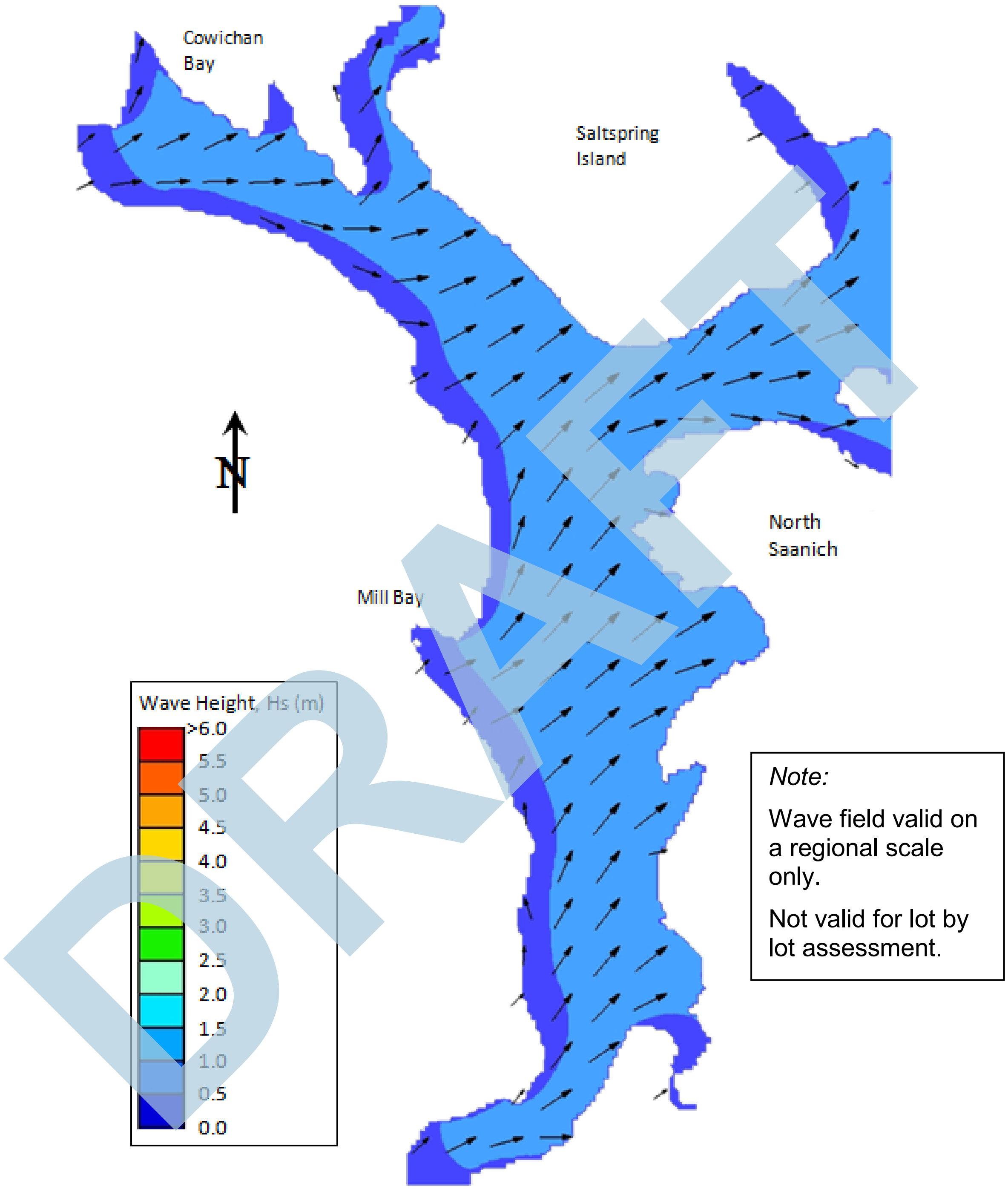


Figure 10: SWAN results for SWAN for the SW peak storm surge scenario for 1m SLR

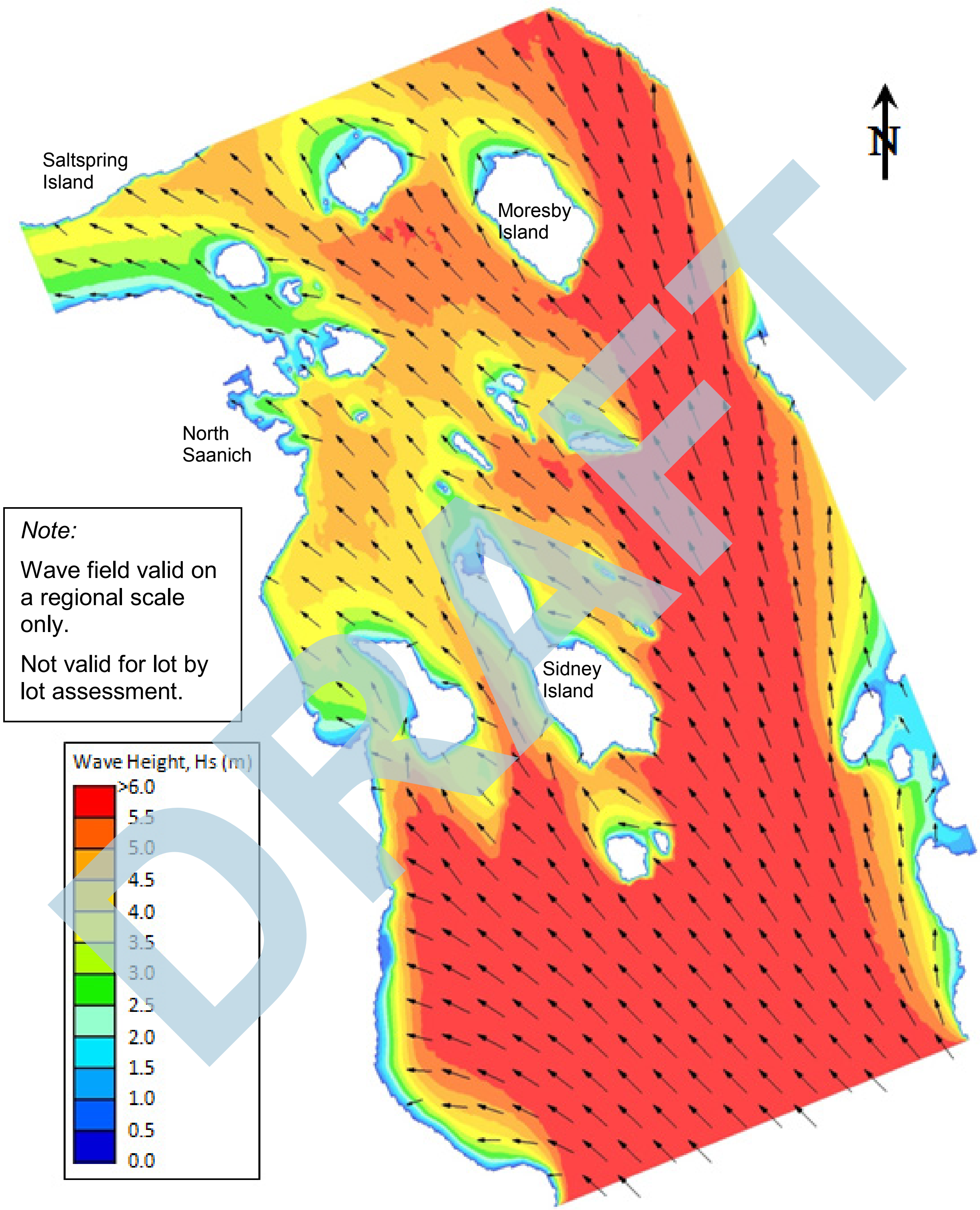


Figure 11: SWAN results for SWAN for the SE peak wind speed scenario for 1m SLR

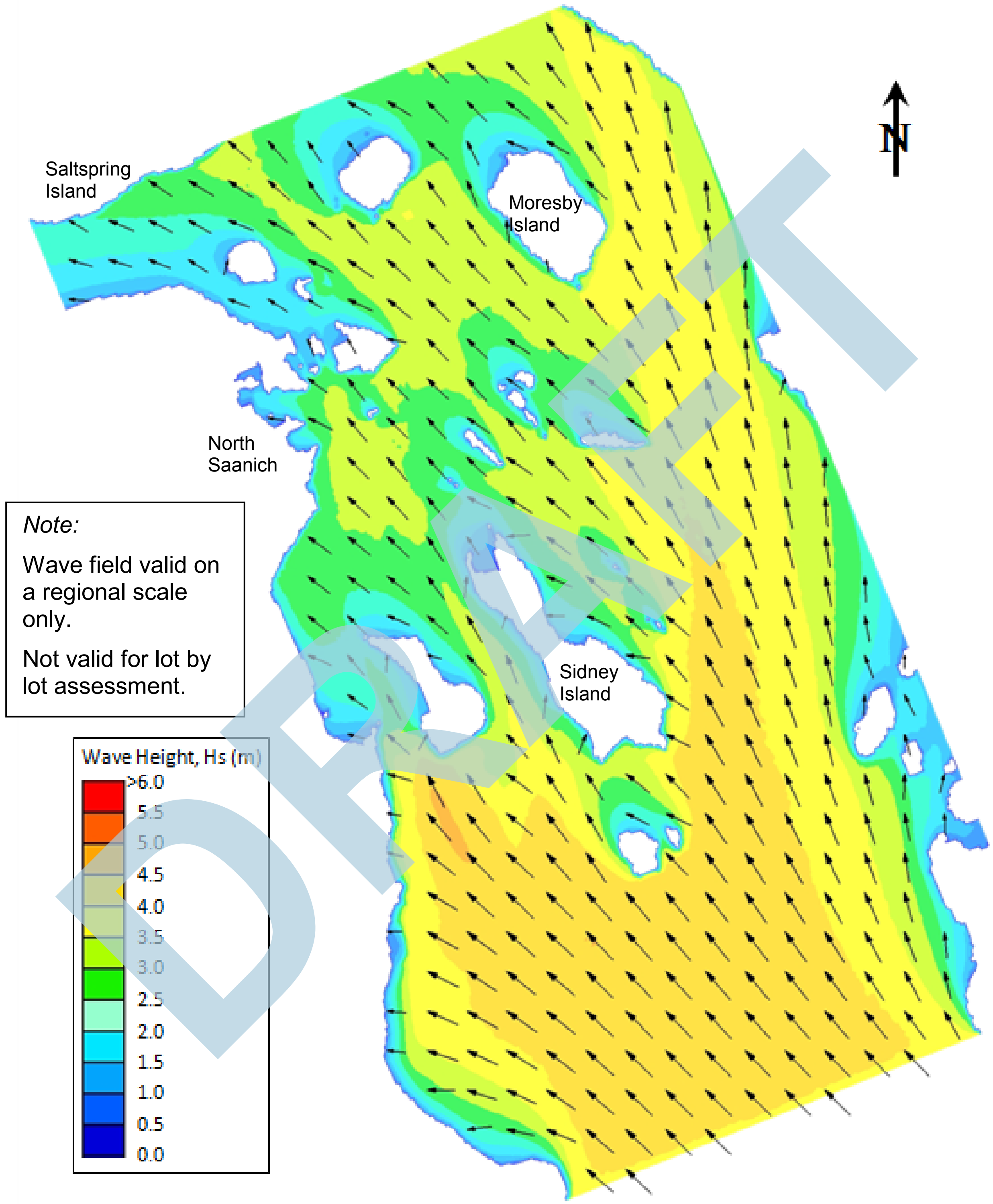


Figure 12: SWAN results for the SE peak storm surge scenario for 1m SLR

APPENDIX B – Nearshore Wave Climate

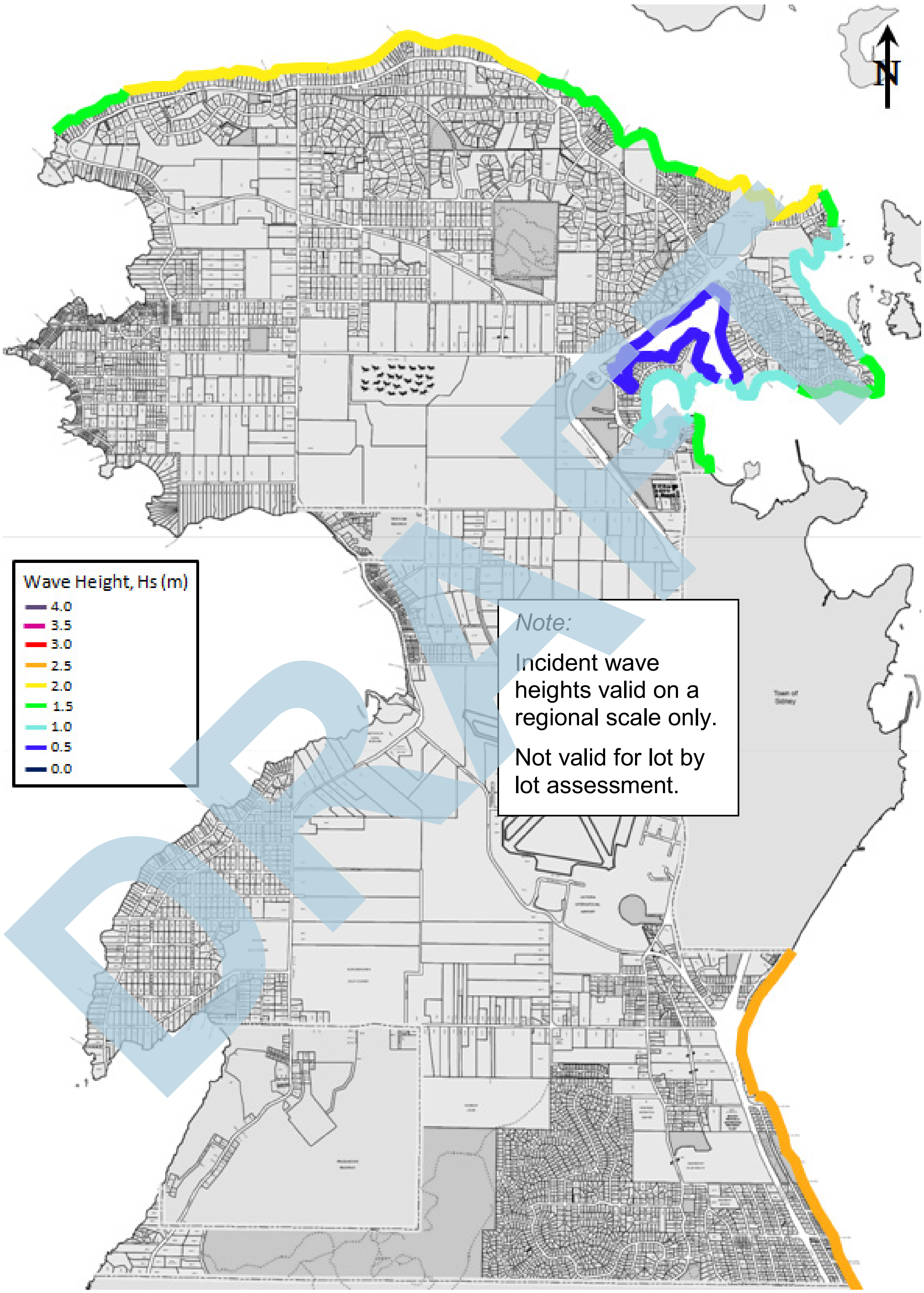


Figure 1: Compiled incident wave heights from SWAN for NE peak wind speed scenario for 0.5m of SLR

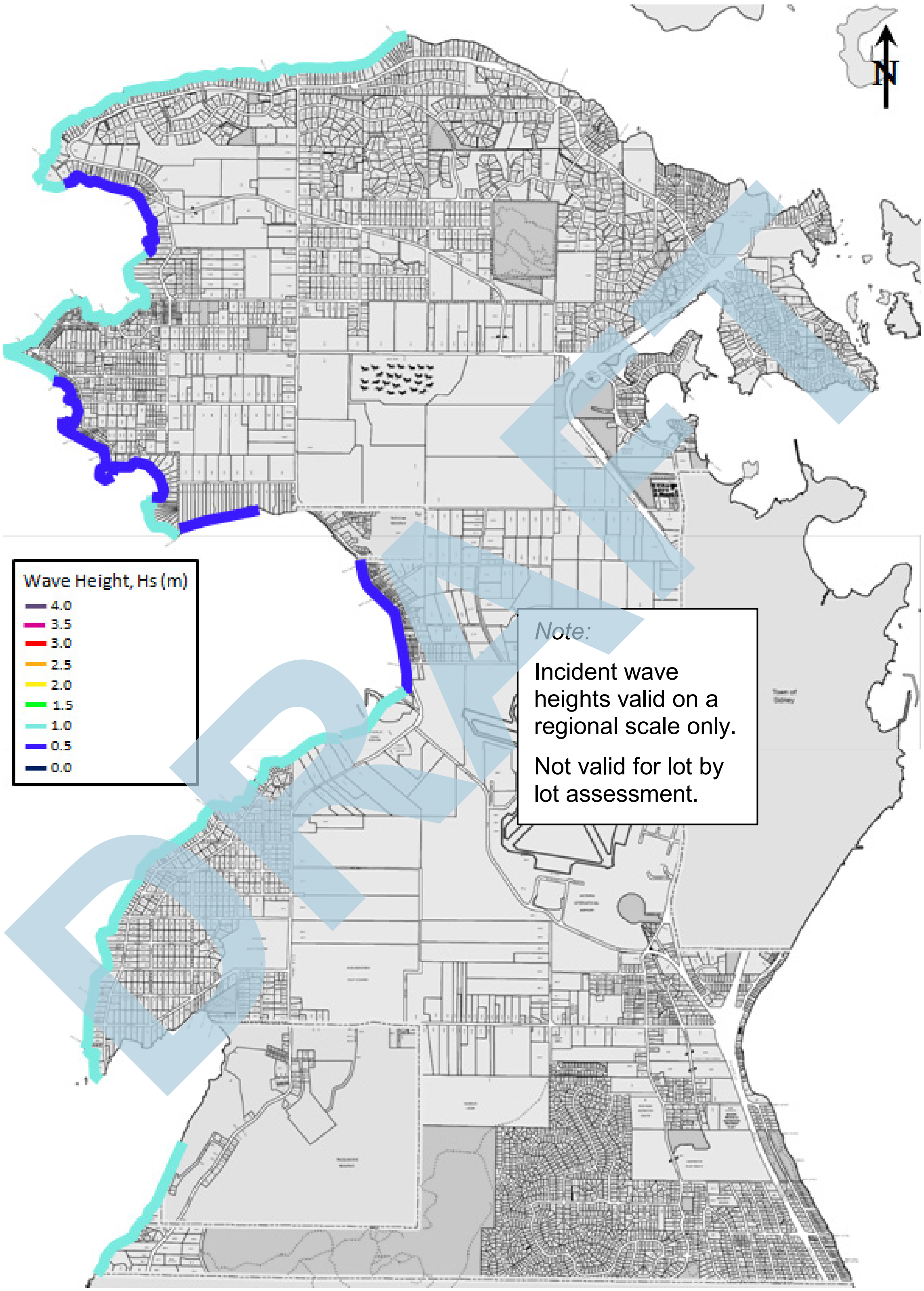


Figure 2: Compiled incident wave heights from SWAN for NW peak wind speed scenario for 0.5m of SLR

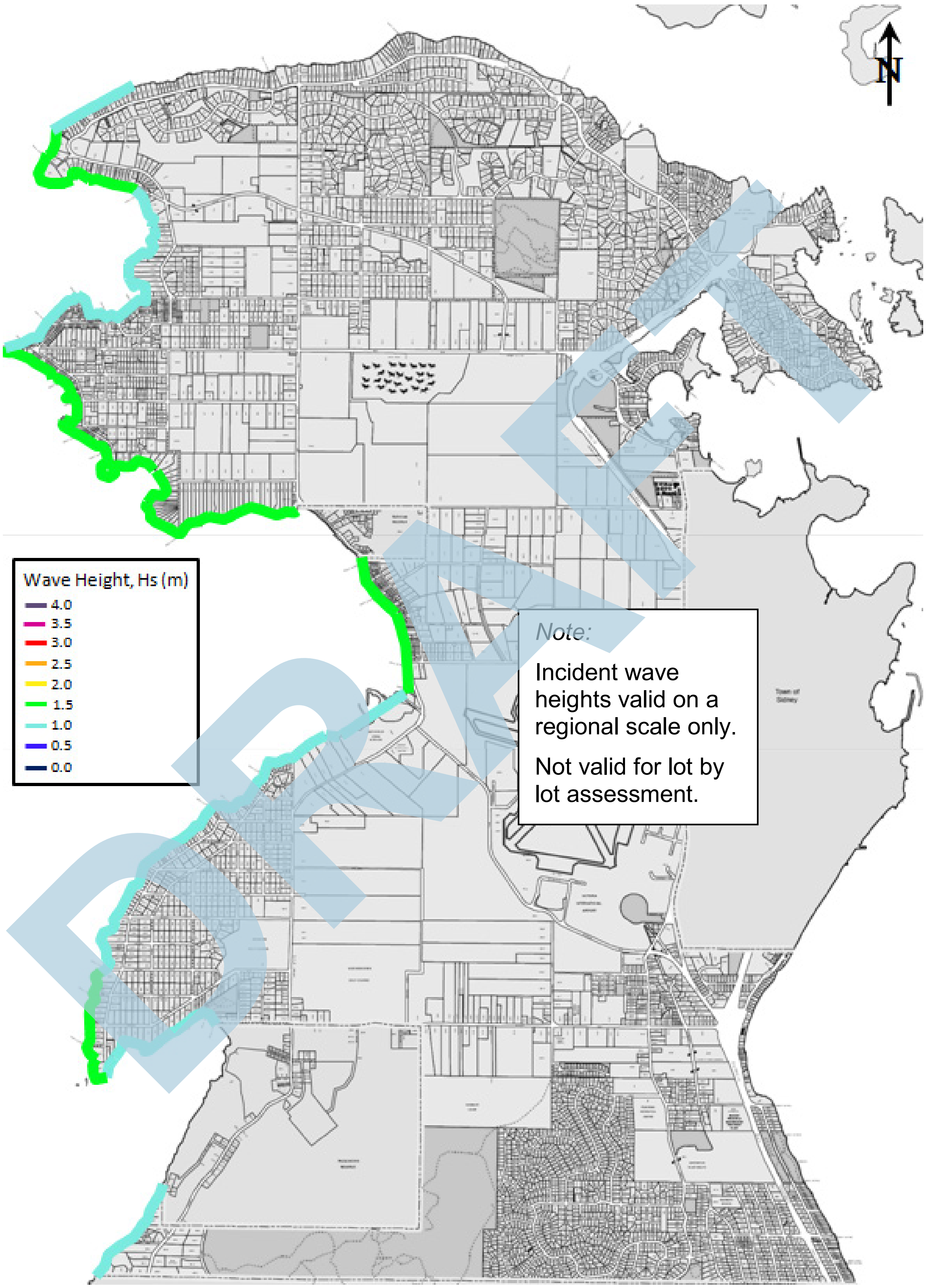


Figure 3: Compiled incident wave heights from SWAN for SW peak wind speed scenario for 0.5m of SLR

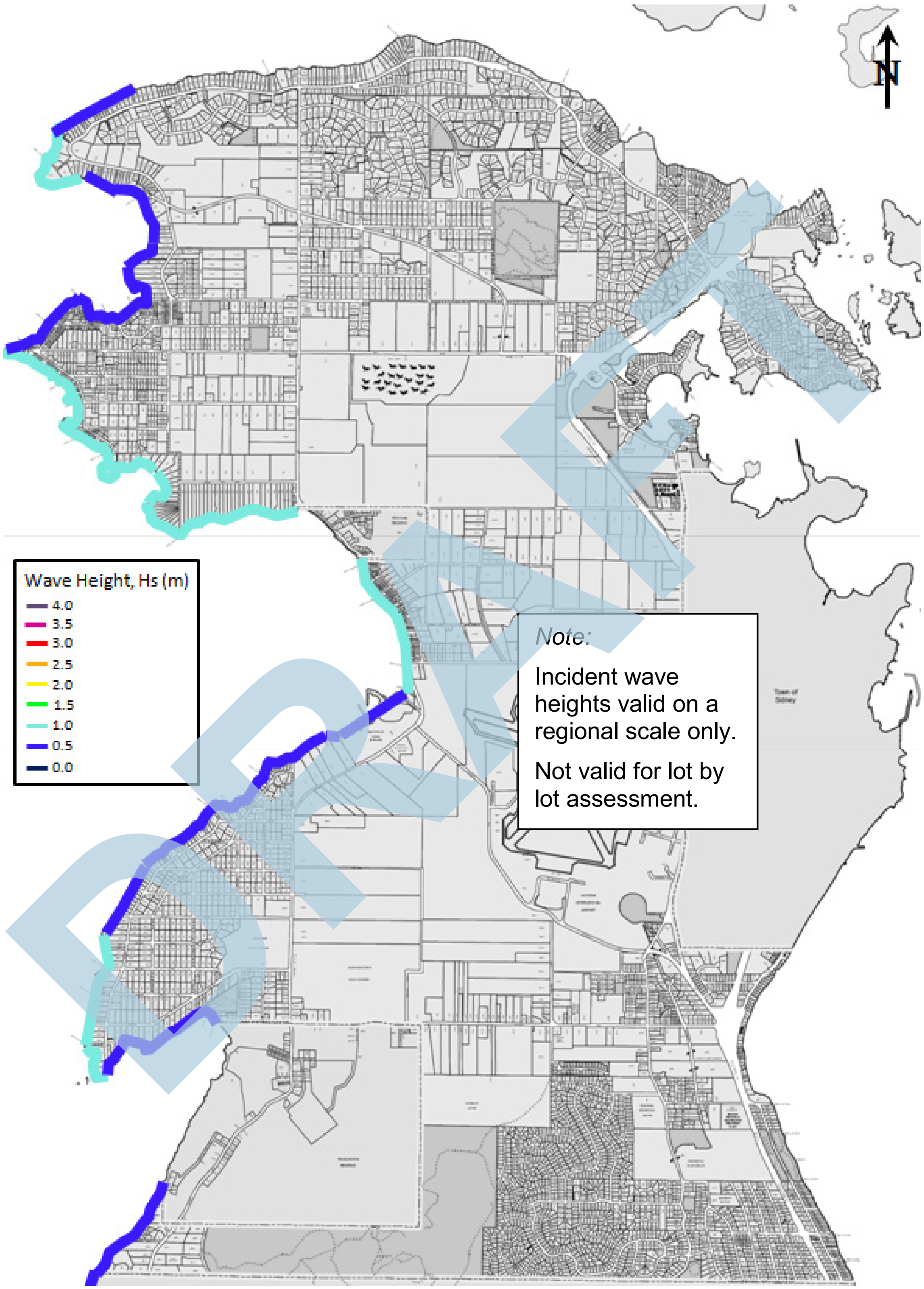


Figure 4: Compiled incident wave heights from SWAN for SW peak storm surge scenario for 0.5m of SLR

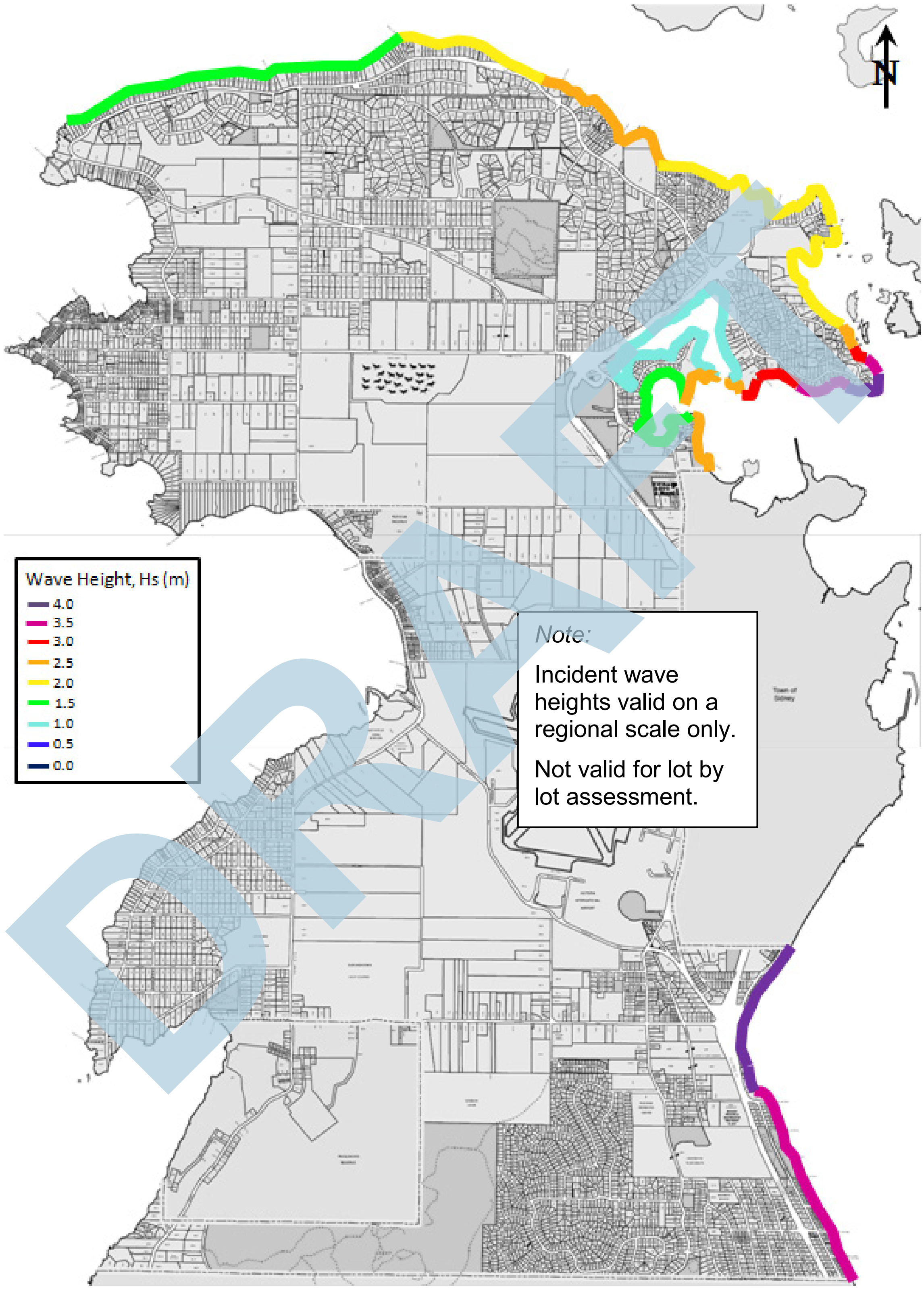


Figure 5: Compiled incident wave heights from SWAN for SE peak wind speed scenario for 0.5m of SLR

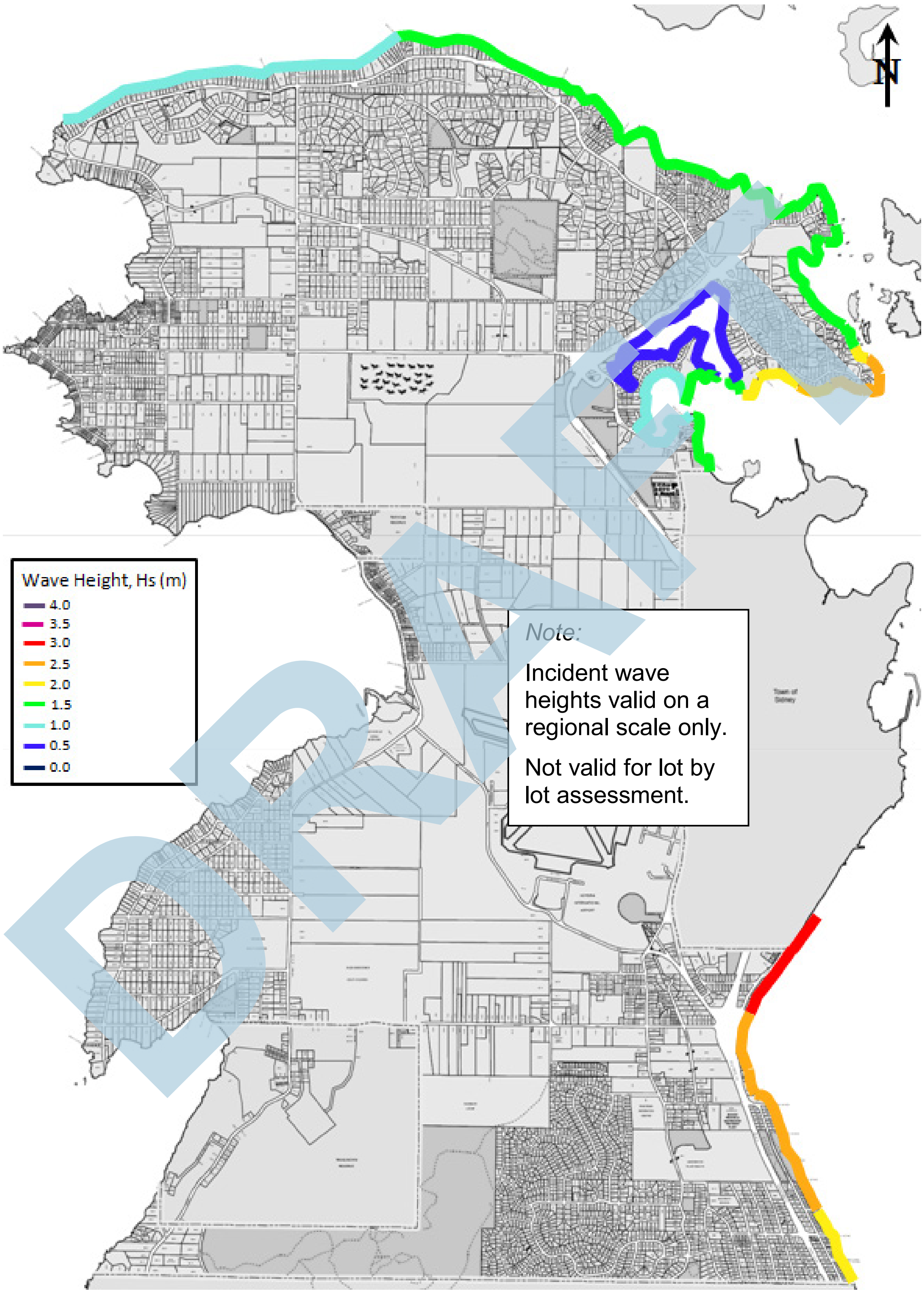


Figure 6: Compiled incident wave heights from SWAN for SE peak storm surge scenario for 0.5m of SLR

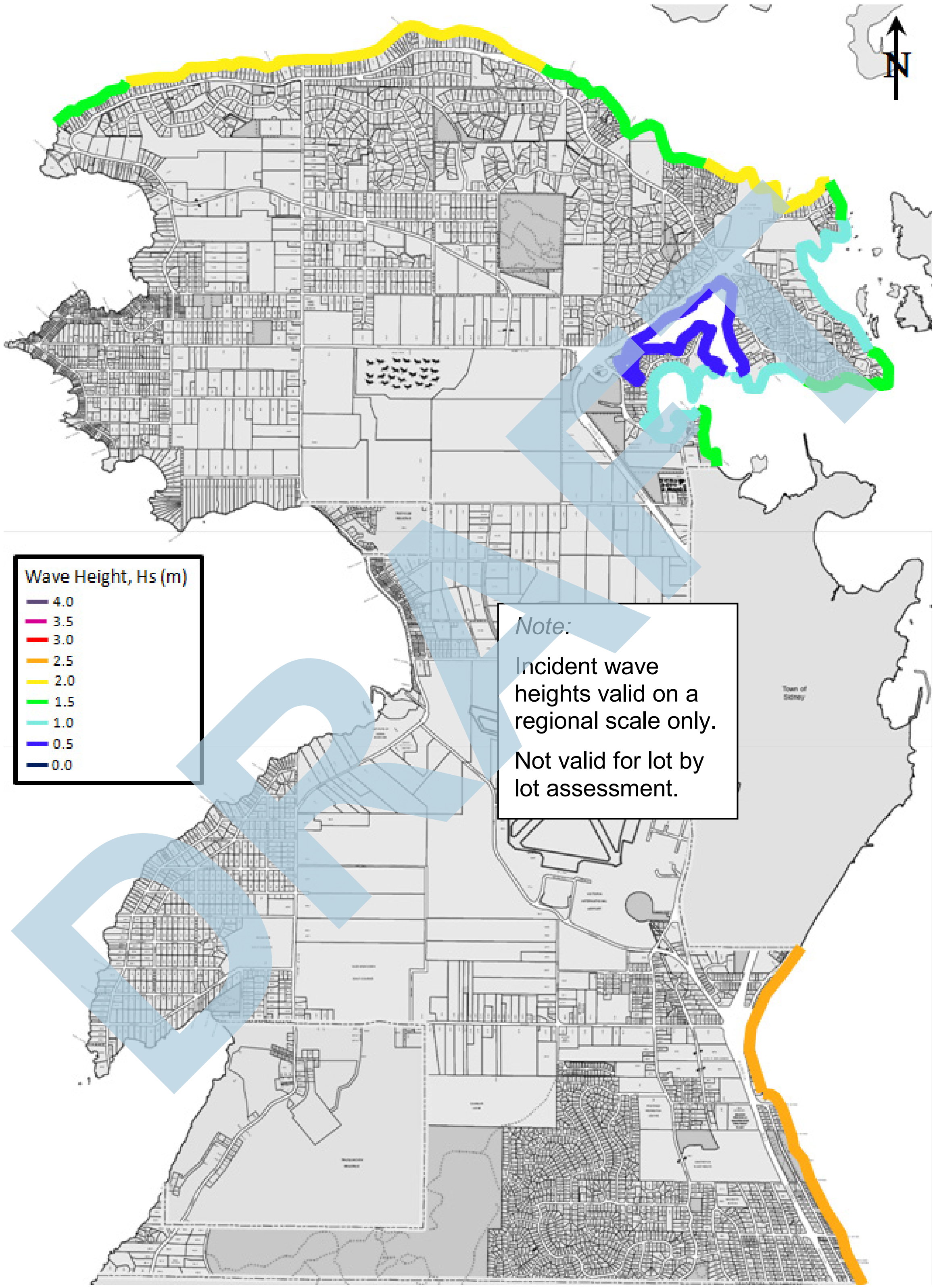


Figure 7: Compiled incident wave heights from SWAN for NE peak wind speed scenario for 1m of SLR

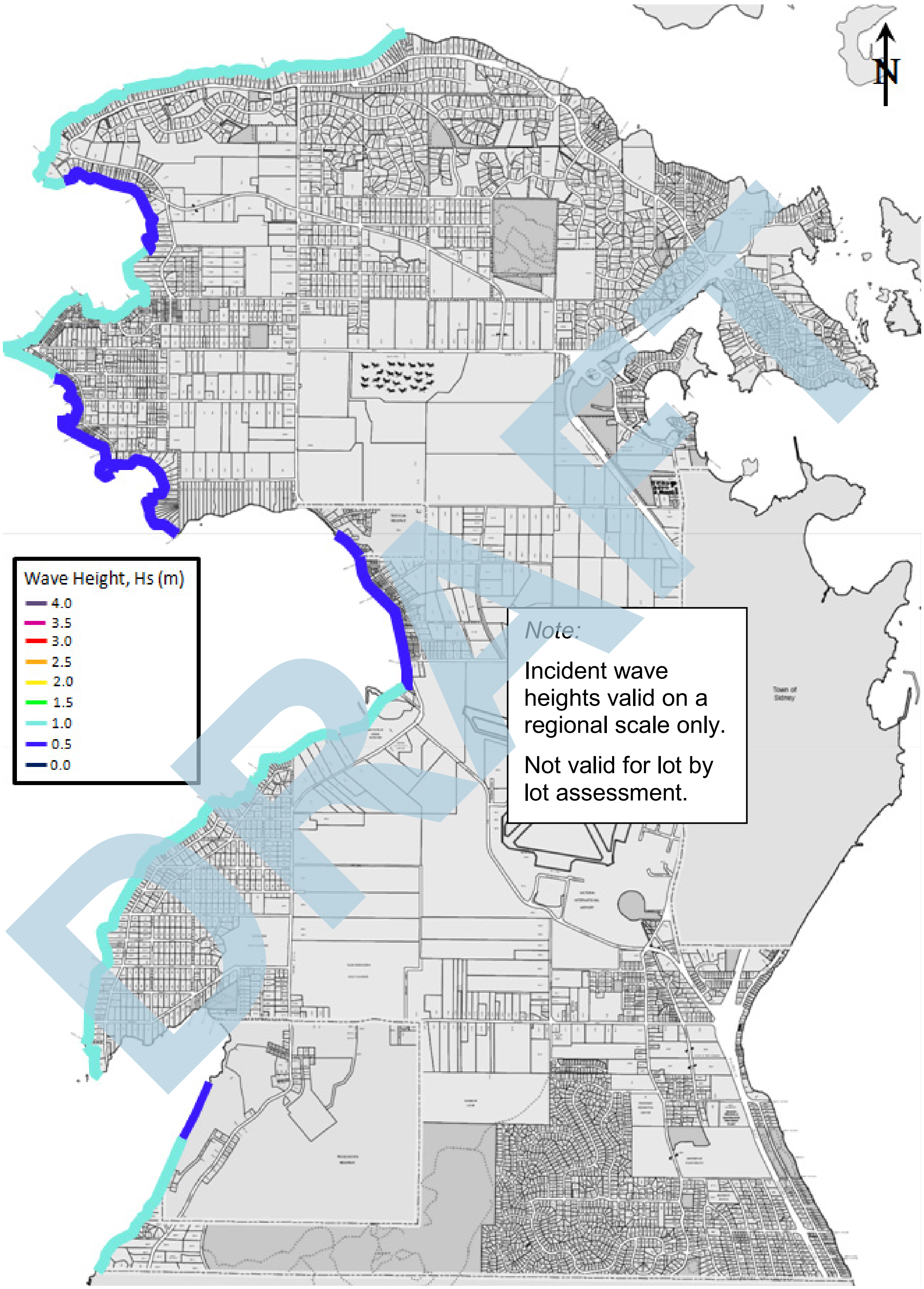


Figure 8: Compiled incident wave heights from SWAN for NW peak wind speed scenario for 1m of SLR

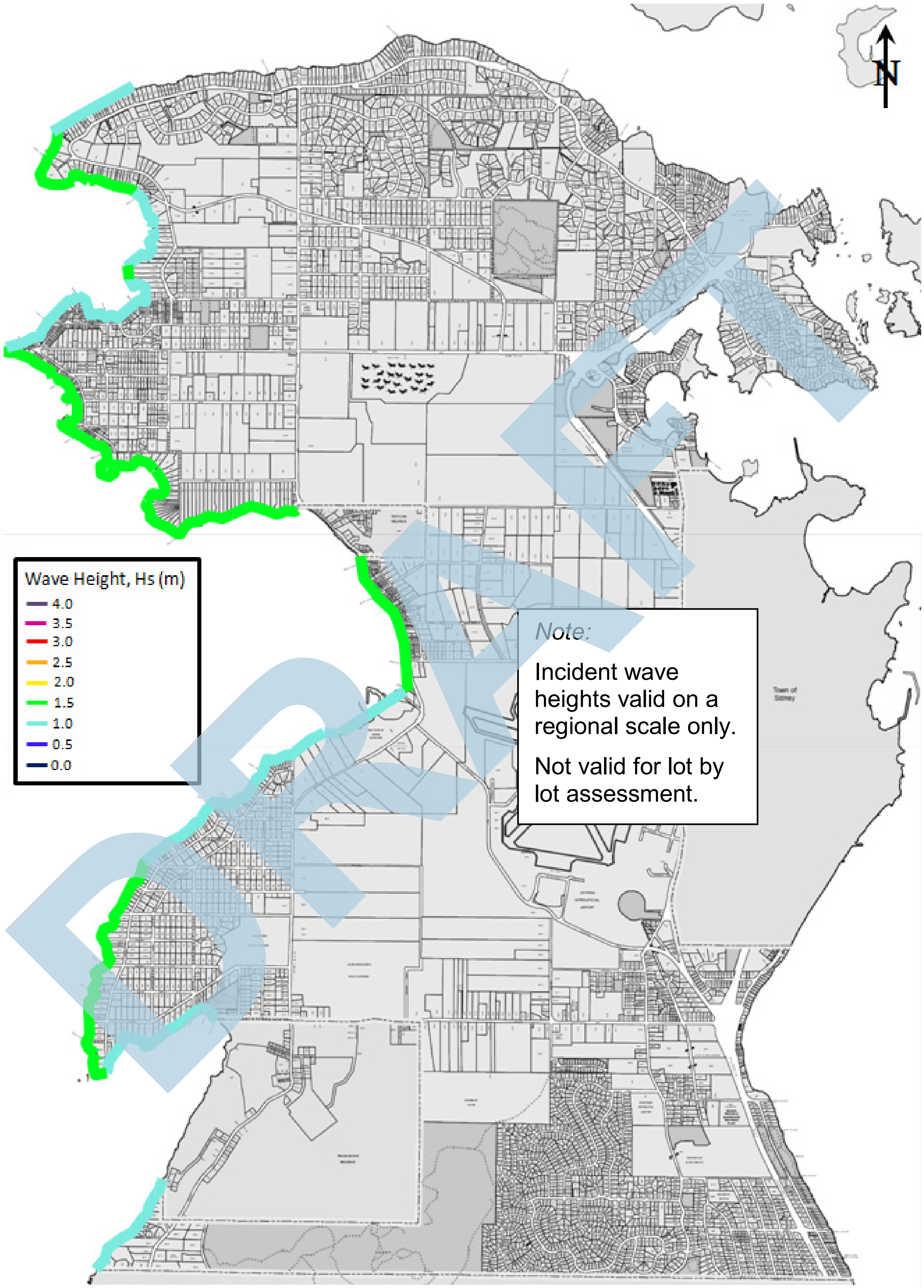


Figure 9: Compiled incident wave heights from SWAN for SW peak wind speed scenario for 1m of SLR

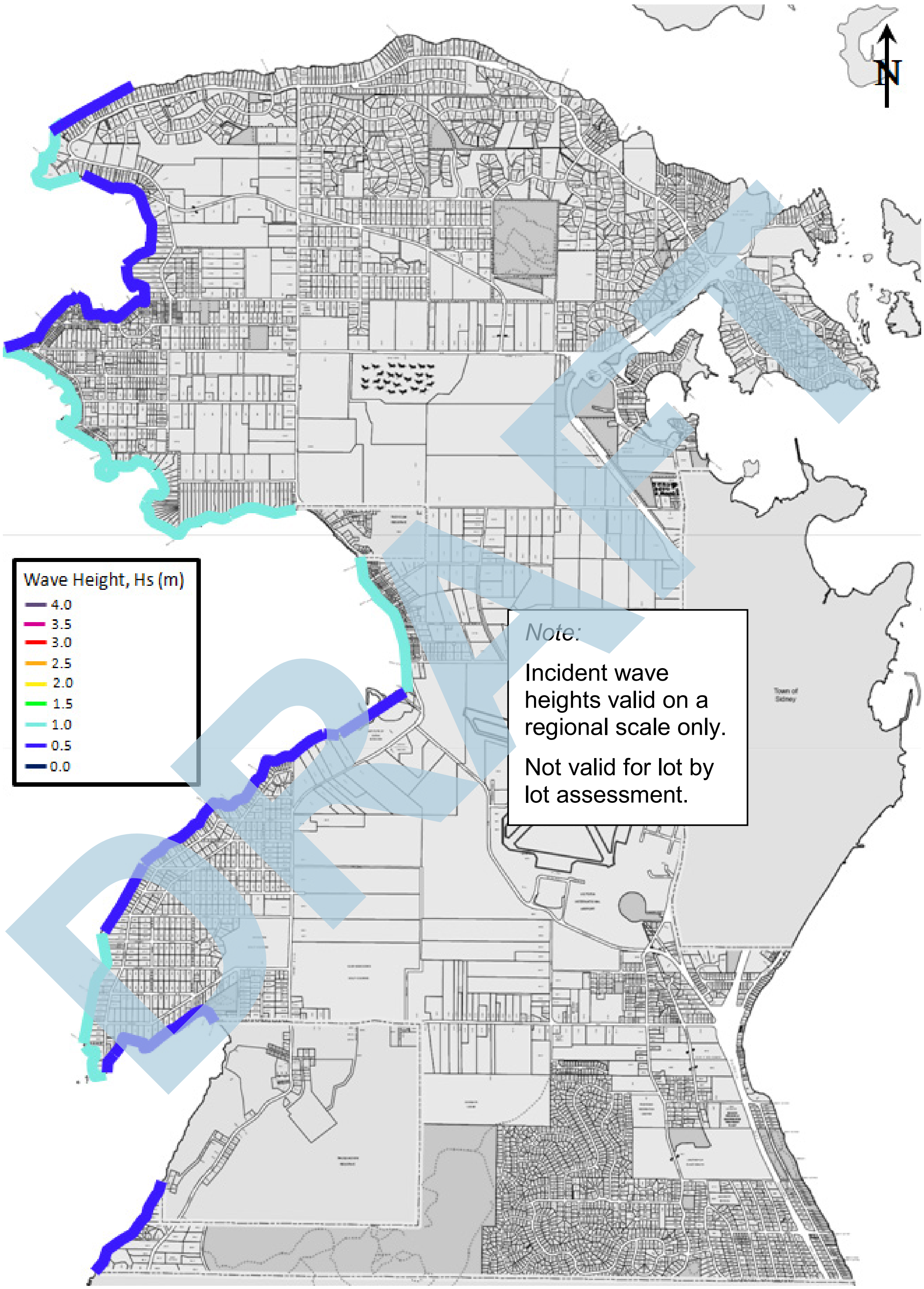


Figure 10: Compiled incident wave heights from SWAN for SW peak storm surge scenario for 1m of SLR

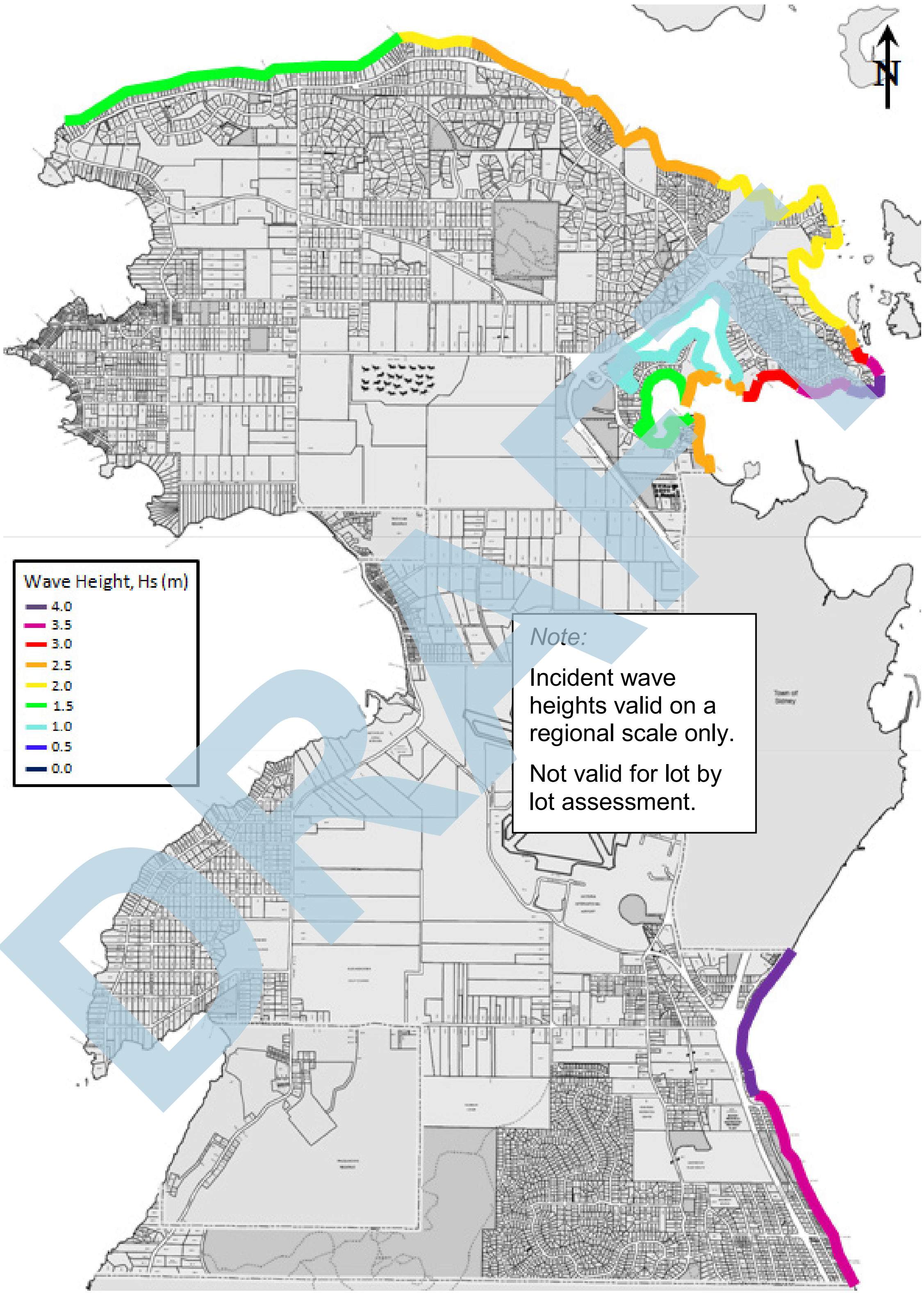


Figure 11: Compiled incident wave heights from SWAN for SE peak wind speed scenario for 1m of SLR

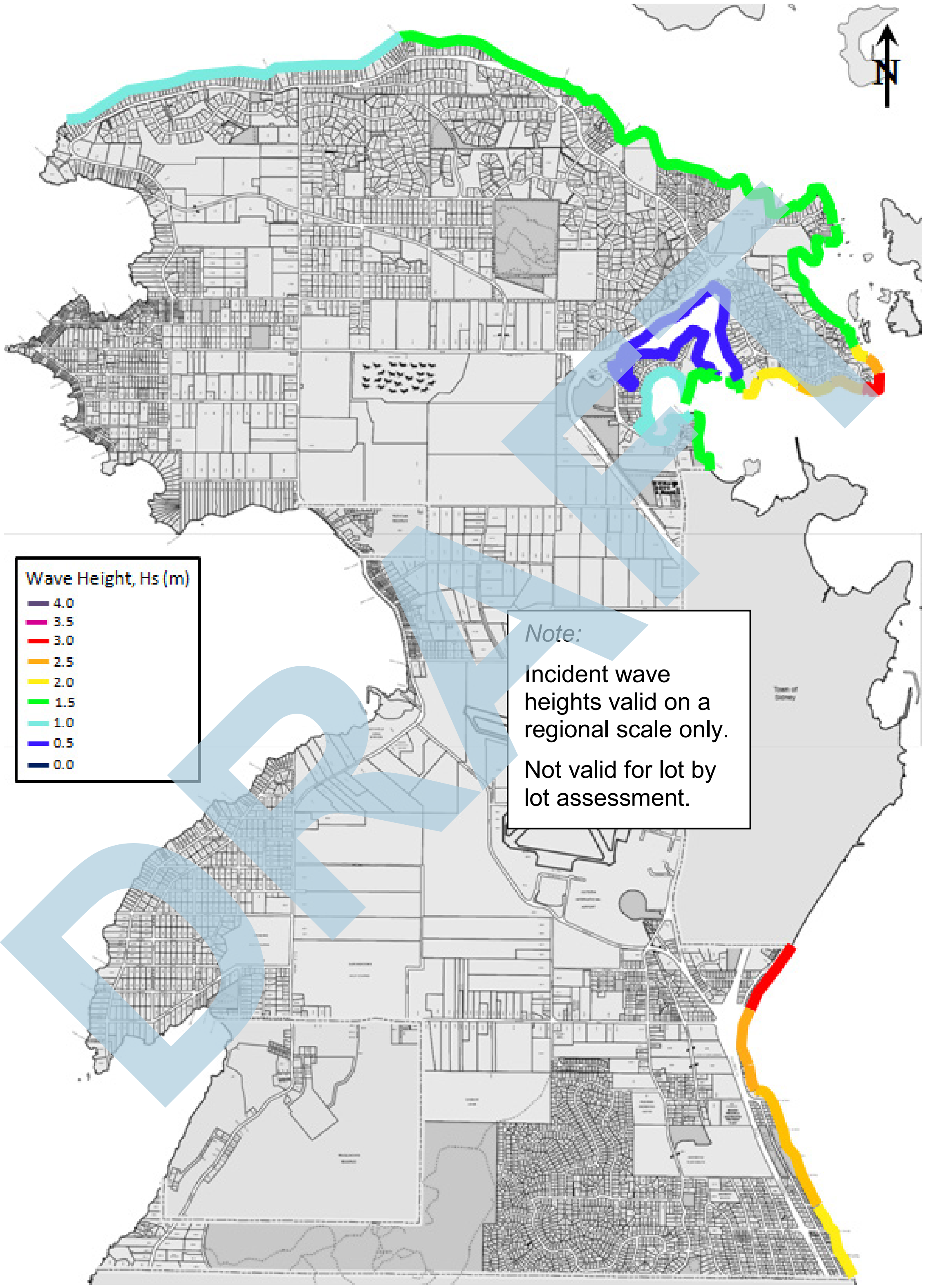


Figure 12: Compiled incident wave heights from SWAN for SE peak storm surge scenario for 1m of SLR

APPENDIX C – Mapped Flood Construction Levels

Flood Construction Level

0.5m SLR

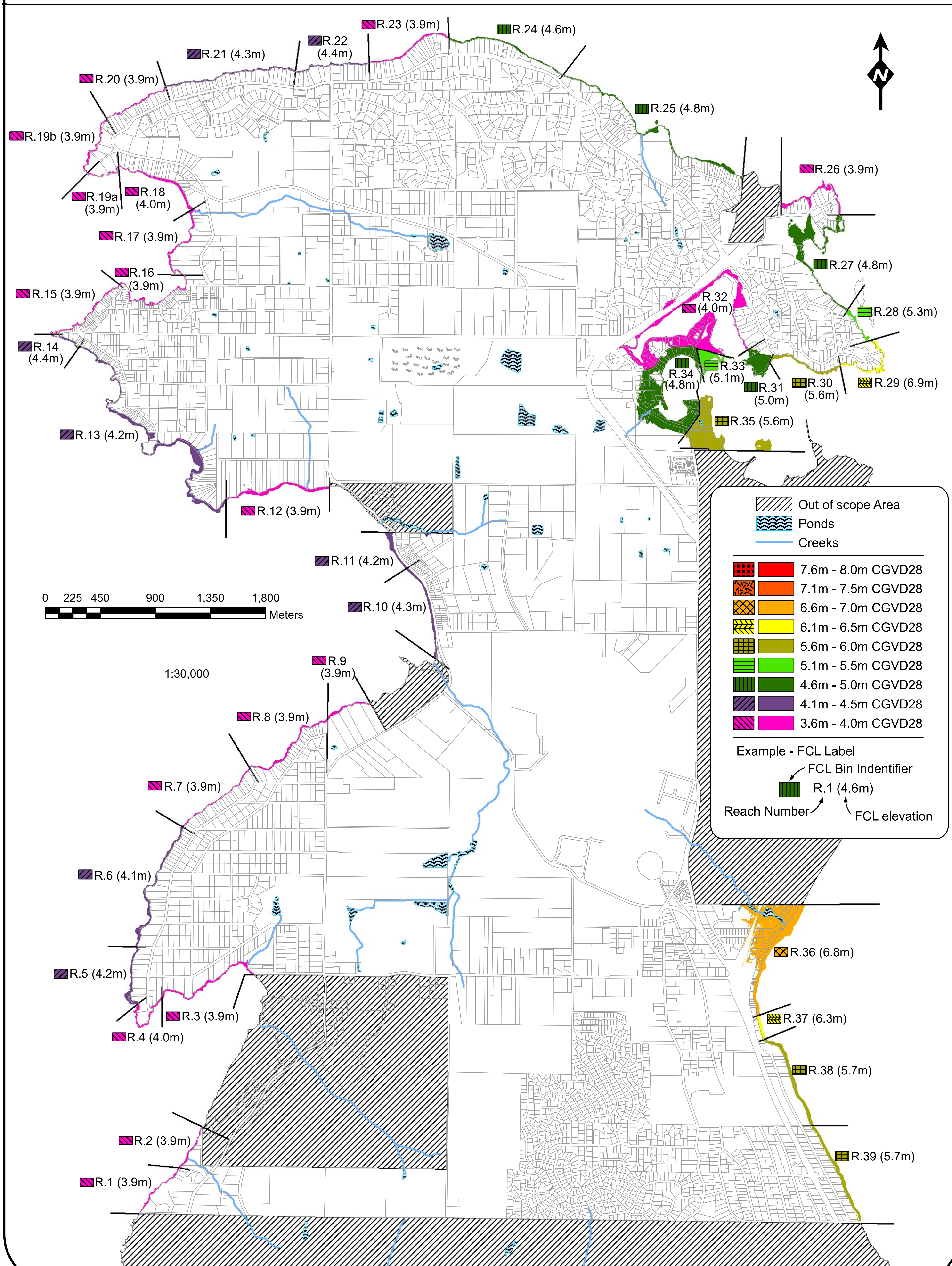
District of North Saanich - Coastal Flood Preparedness Planning

This map displays the estimated governing Flood Construction Level (FCL) for a 1:500 AEP designated storm case, and is defined as:
[1]FCL = HHWLT + SLR + Storm surge + Wave effect + Freeboard, where:

- FCL – elevation in m, CGVD28
- HHWLT – Higher High Water Large Tide, 1.5m CGVD28 (3.7m Chart Datum at Swartz Bay
- SLR – 0.5 m sea level rise allowance
- Storm surge – varies around shoreline, depending on site exposure.
- Wave effect – wave-shoreline interaction, corresponding to the start of potential shoreline damage or risk to people
- Freeboard – 0.6 m vertical allowance

Reach demarcation lines are approximate.
[1]SNC-Lavalin Inc. "Flood Construction Levels for 0.5m and 1.0m Sea Level Rise". Document No. 634533-3000-41ER-0001.

Information shown on these drawings is compiled from numerous sources and may not be complete or accurate, the District of North Saanich is not responsible for any errors, omissions or deficiencies in these drawings.



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Flood Construction Level

1m SLR

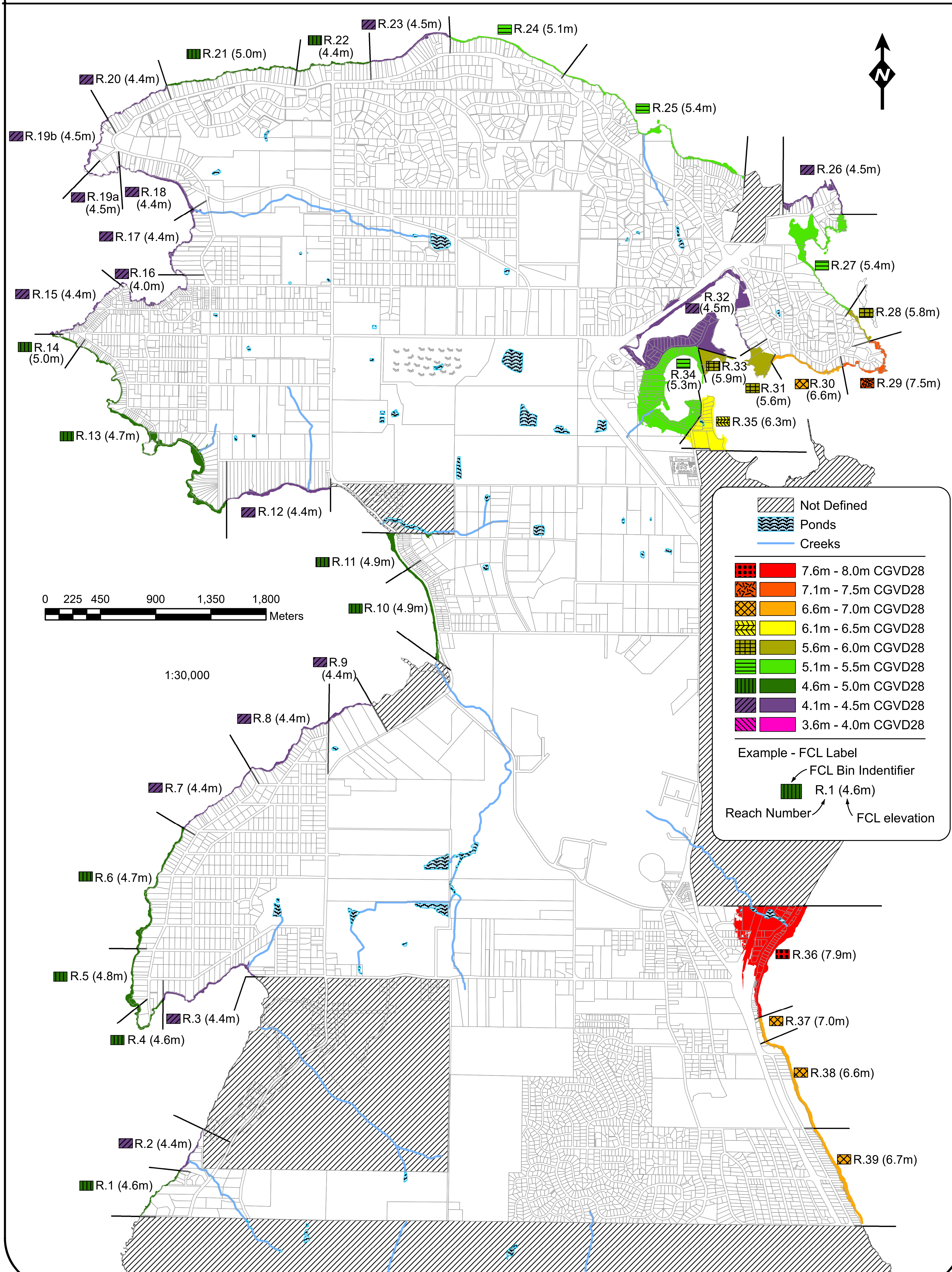
District of North Saanich - Coastal Flood Preparedness Planning

This map displays the estimated governing Flood Construction Level (FCL)[1] for a 1:500 AEP Designated Storm case, and is defined as:
FCL = HHWLT + SLR + Storm surge + Wave effect + Freeboard, where:

- FCL – elevation in m, CGVD28
- HHWLT – Higher High Water Large Tide,1.5m CGVD28 (3.7m Chart Datum) at Swartz Bay
- SLR – 1.0 m sea level rise allowance
- Storm surge – varies around shoreline, depending on site exposure
- Wave effect – wave-shoreline interaction, corresponding to the start of potential shoreline damage or risk to people
- Freeboard – 0.6 m vertical allowance

Reach demarcation lines are approximate.

[1]SNC-Lavalin Inc. "Flood Construction Levels for 0.5m and 1.0m Sea Level Rise". Document No. 634533-3000-41ER-0001.



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APPENDIX D – Sensitivity Test: Overtopping Rates

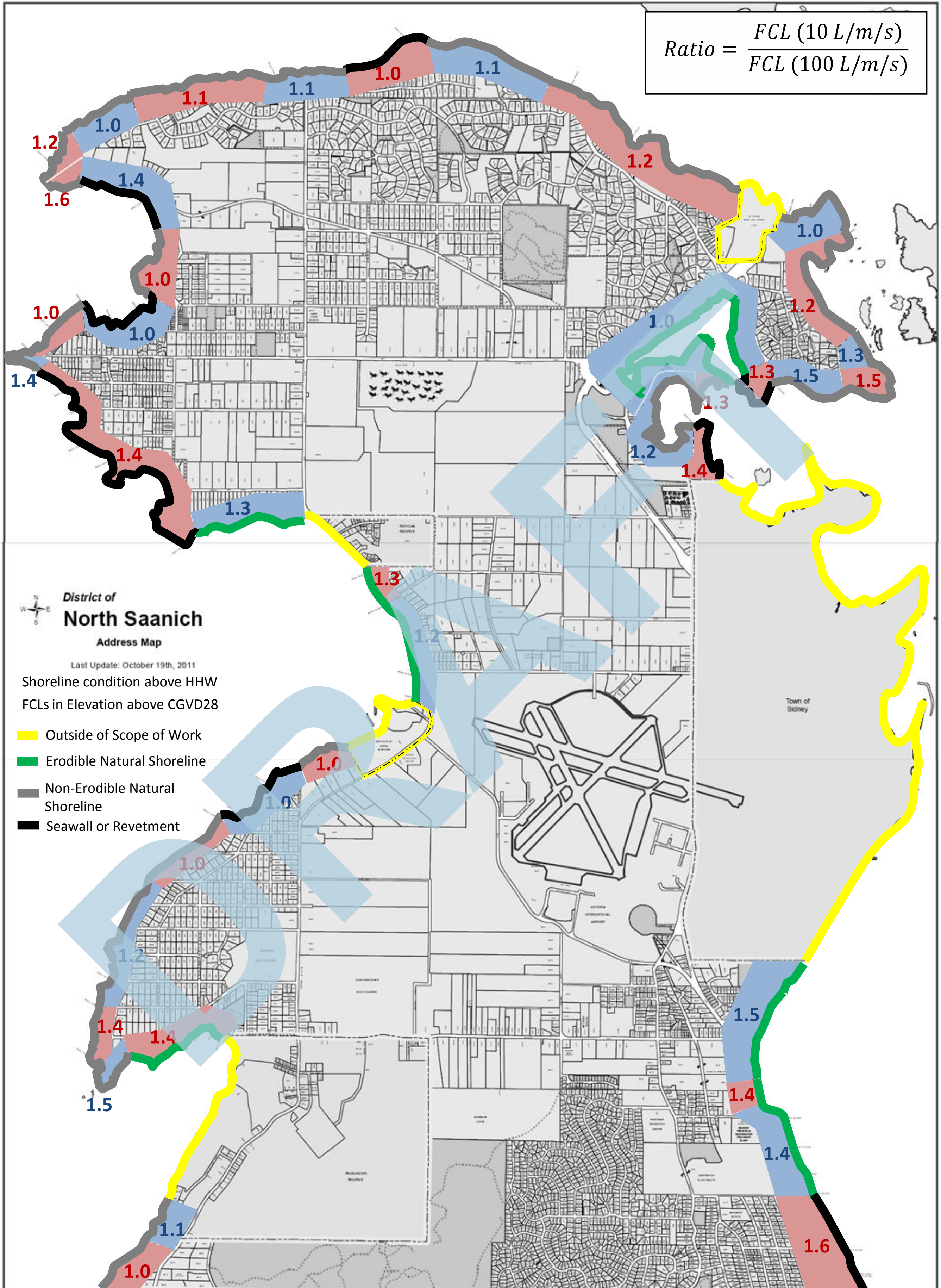

Figure 1: Sensitivity of FCL's to Overtopping Threshold. Ratio on Map = FCL (10 L/m/s) / FCL (100 L/m/s)