moffatt & nichol

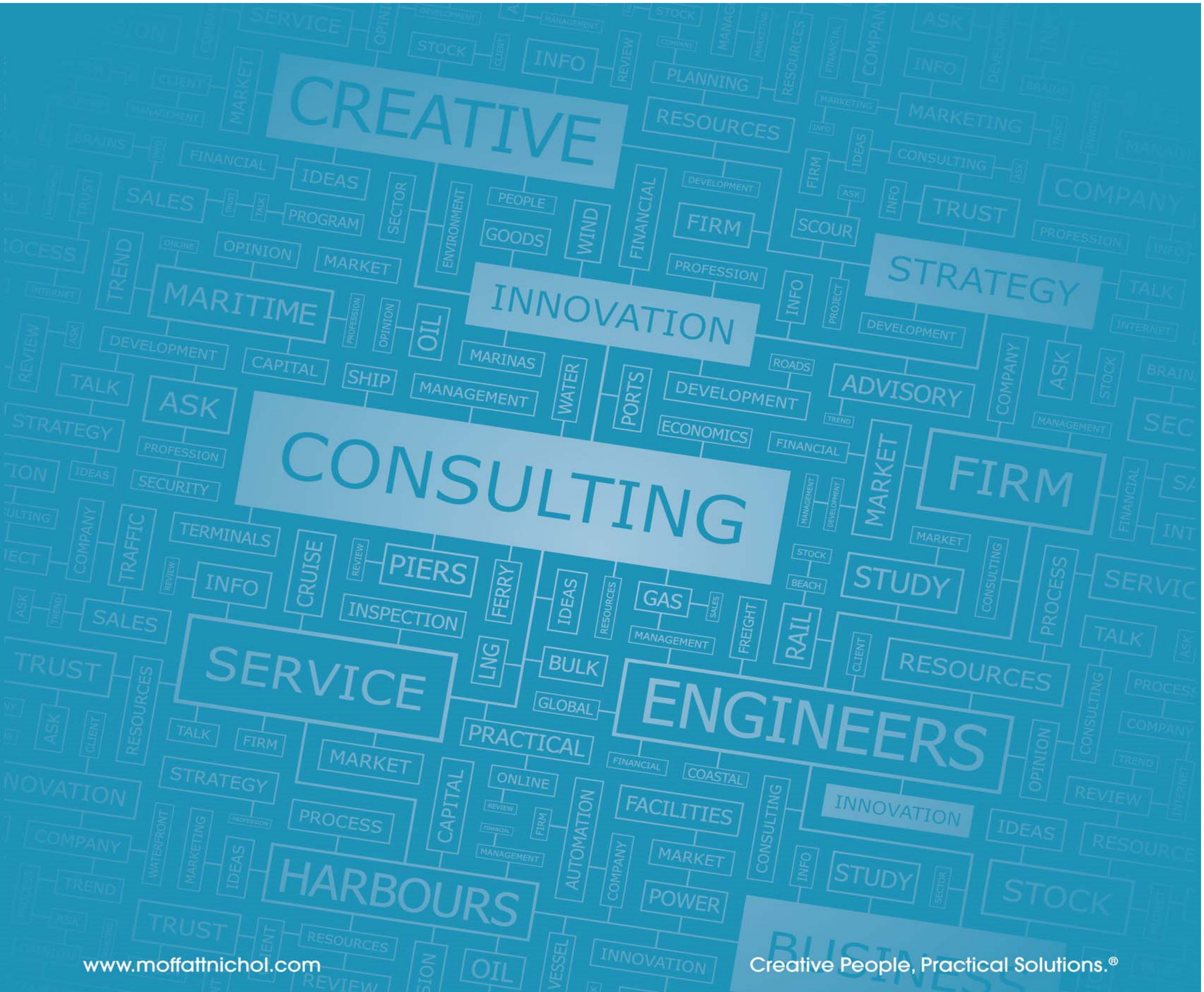
Columbia River Project Water Use Plan

CLBWORKS-5A Kinbasket: Valemount Marina Ramp Extension

Wind & Wave Analysis

PRODUCED FOR BC HYDRO

SEPTEMBER 2018



Document Verification

Client	BC Hydro
Project name	Columbia River Project Water Use Plan
Document title	CLBWORKS-5A Kinbasket: Valemount Marina Ramp Extension
Document subtitle	Wind & Wave Analysis
Status	Report
Date	September 14, 2018
Project number	9598-01
File reference	

Revision	Description	Issued by	Date	Checked
00	Final Report	B. Tehranirad	September 14, 2018	M. Jorgensen

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Glossary

BCH	BC Hydro
CDEM	Canadian Digital Elevation Model
CGVD28	Canadian Geodetic Vertical Datum of 1928
EVA	Extreme Value Analysis
GD	Geodetic Datum
MN	Moffatt & Nichol
NAD83	North American Datum of 1983
NRCan	Natural Resources Canada
SW	Spectral Wave {model}
UTM	Universal Transverse Mercator {Projection}

Executive Summary

This memo presents findings of a wind-wave analysis conducted for the Valemount Marina. Since the latest expansion of the marina, the following questions have arisen:

1. Extension and orientation of the longer ramp means that northerly winds cross the ramp and make landing difficult.
2. Erosion of the rubble mound breakwater on the southern side.

Wind Conditions for Landing

The first item is related to use of the boat launch ramp. Prior to the extension of the ramp, the ramp was aligned approximately parallel to the road along the lakeshore. In order to extend the launch ramp to a lower lake level and meet the grades required for usage, a turnout was incorporated and the lower portion of the ramp aligned approximately east-west. A ramp extension with a different alignment would not have been feasible as it would have been cost prohibitive (would have required extensive amounts of cut and fill), or would have resulted in other usage problems, i.e. the ramp would have been too long.

The solution may be to advise boaters about wind conditions during periods of low lake level, i.e. access to the lake prior to the peak boating season. Based on PIANC guidance, it is estimated that times, when conditions for landing are untenable, could be on the order of a few hours out of the shoulder season up to 5 days of time cumulatively for boaters requiring ideal conditions for launching and landing.

If landing is related to both wind and wave conditions, a log boom or floating wave attenuator could be incorporated to shield the ramp from waves developing over the lake. A simple mooring system could be utilized to keep the wave attenuator in position alongside the ramp, enabling it to move vertically with changes in lake level. Another solution could be to upgrade the lower ramp with a rail-mounted pontoon, which would enable users to come alongside a boarding float when launching and landing at the ramp.

Rubble Mound Breakwater Erosion

Following construction of the marina extension, erosion was observed along the edge of the rubble mound breakwater. Atek was commissioned to conduct a site topographic and bathymetric survey in 2008, which was compared to the post-constructed site survey from 2007. Areas of erosion were identified along the outside face of the rubble mound breakwater and along the inside face as well.

The areas where the breakwater profile was affected were all up near the crest of the breakwater around elevation 754.0. If the erosion was wave-related, it means that the damage is likely to have happened within the time span from August to November where the lake level is up around this elevation. There are several other causes and effects that could have contributed to the damage, which are discussed briefly in the present analysis. These include slumping, segregation, avalanching, slope failure, and localized rock sliding.

The specific cause of the damage is not known in detail at this time. The present analysis, therefore, evaluates wave action as the potential cause of the erosion.

A new site survey was conducted in May 2018 to determine if the damage is progressive or if the material placed on the slopes has stabilized. The survey data indicated that the crest of the bank along the access road may have been subject to some erosion or slumping of the shore protection material. Another area of erosion or lowering of the lakebed elevation is at the toe of the launch ramp. It also appears that material has eroded or slumped around the tip of the breakwater. The recent survey shows other areas as having raised grades, which could be due to siltation or differences in survey techniques.

At this time, the indication is that the erosion may have been associated with the slope protection material being out of spec and not placed per the design requirements. This is supported by the indicative failure mechanisms observed, which include:

- Wave-induced erosion, supporting the fact that the placed material was undersized.
- Examination of post-construction photos, which indicate that portions of the material placed during construction may have been subject to segregation. This commonly happens if material is dumped at the top of the slope and rolls down, whereas the appropriate method of construction is to build the slope starting at the toe and working up.
- Avalanching, which can cause material to slide down along the slope if lower portions of the slope are eroded and/or if the material was placed too steeply.

1. Introduction

Moffatt & Nichol (MN) was retained by BC Hydro (BCH) to develop a wind-wave analysis for the Valemount Marina in order to address the following items:

- Extension and orientation of the longer ramp means that northerly winds cross the ramp and make landing difficult.
- Erosion of the rubble mound breakwater on the southern side.

1.1. Background Information

Kinbasket Lake is a reservoir on the Columbia River in southeast British Columbia at Valemount, BC, north of Revelstoke and Golden. The reservoir was created by the construction of the Mica Dam. The lake includes two reaches, Columbia Reach to the south and Canoe Reach to the north. The town of Valemount is located at the northern end of Canoe Reach, and the Valemount Marina is located on the lakeshore approximately 23 kilometers southeast of Valemount. An aerial view of the marina is shown in Figure 1-1. The northern portion of Canoe Reach and locations of Valemount, BC and Valemount Marina are shown in Figure 1-2.

FIGURE 1-1: VALEMOUNT MARINA AERIAL VIEW (IMAGE COURTESY OF WWW.VALEMOUNTMARINA.COM).

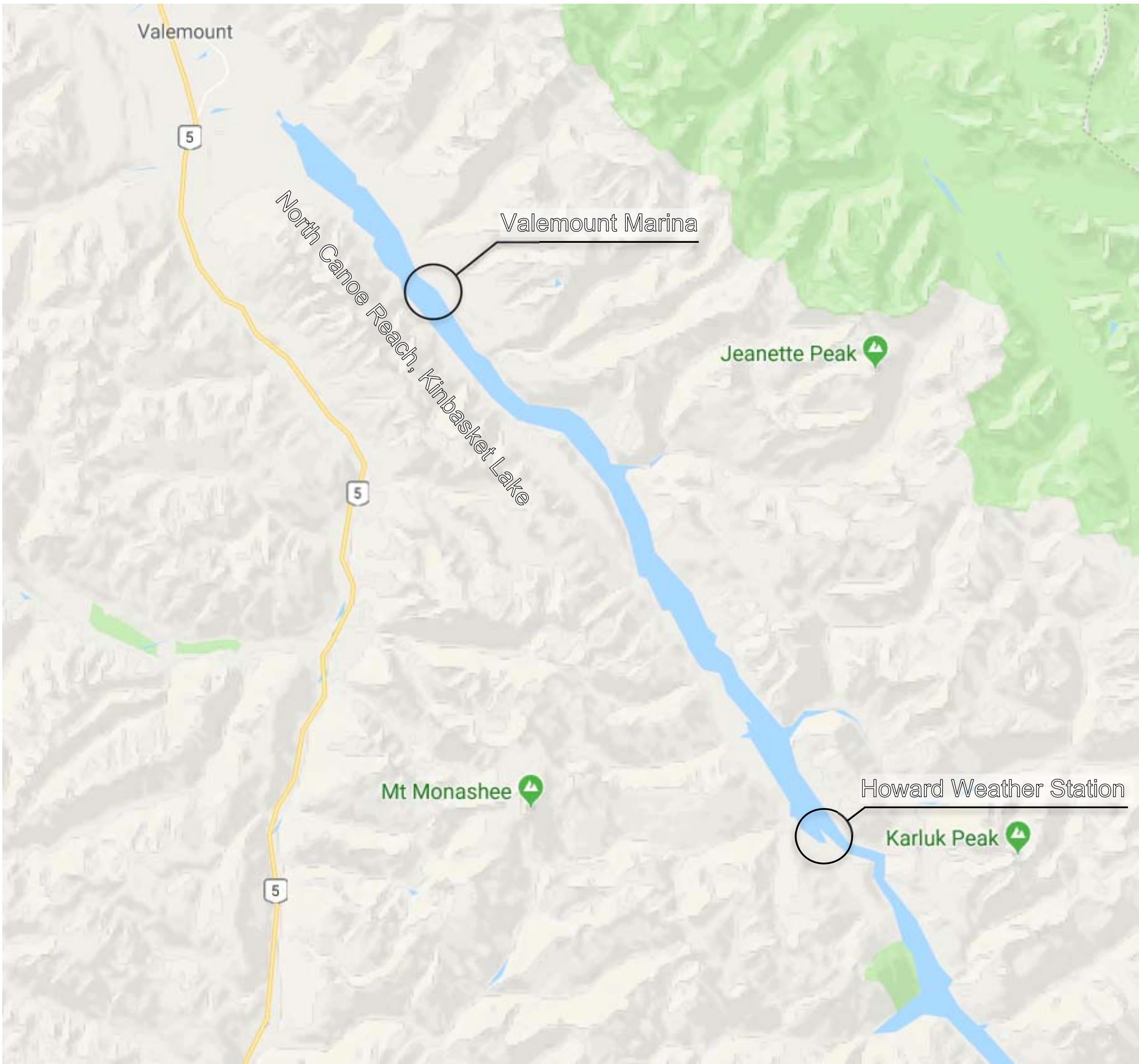

FIGURE 1-2: OVERVIEW OF NORTH CANOE REACH, VALEMOUNT, BC, AND VALEMOUNT MARINA.

2. Basis of Analysis

The main elements needed for the wind-wave analysis are described in the following. These include the lake topography, wind statistics, and lake water levels.

2.1. Topographic Data

Moffatt & Nichol developed a digital elevation model (DEM) with an extent covering Kinbasket Lake North Canoe Reach and the Valemount Marina project site. The planar reference is NAD83, UTM Zone 11 in meters with elevation reference to CGVD28 in meters. Topographic elevation data was acquired from the NRCan CDEM. The data has a resolution of 0.75 arc-seconds, which corresponds to approximately 20-meter spacing between grid points. Figure 2-1 shows elevation contours of the CDEM topographic data superimposed on satellite imagery.

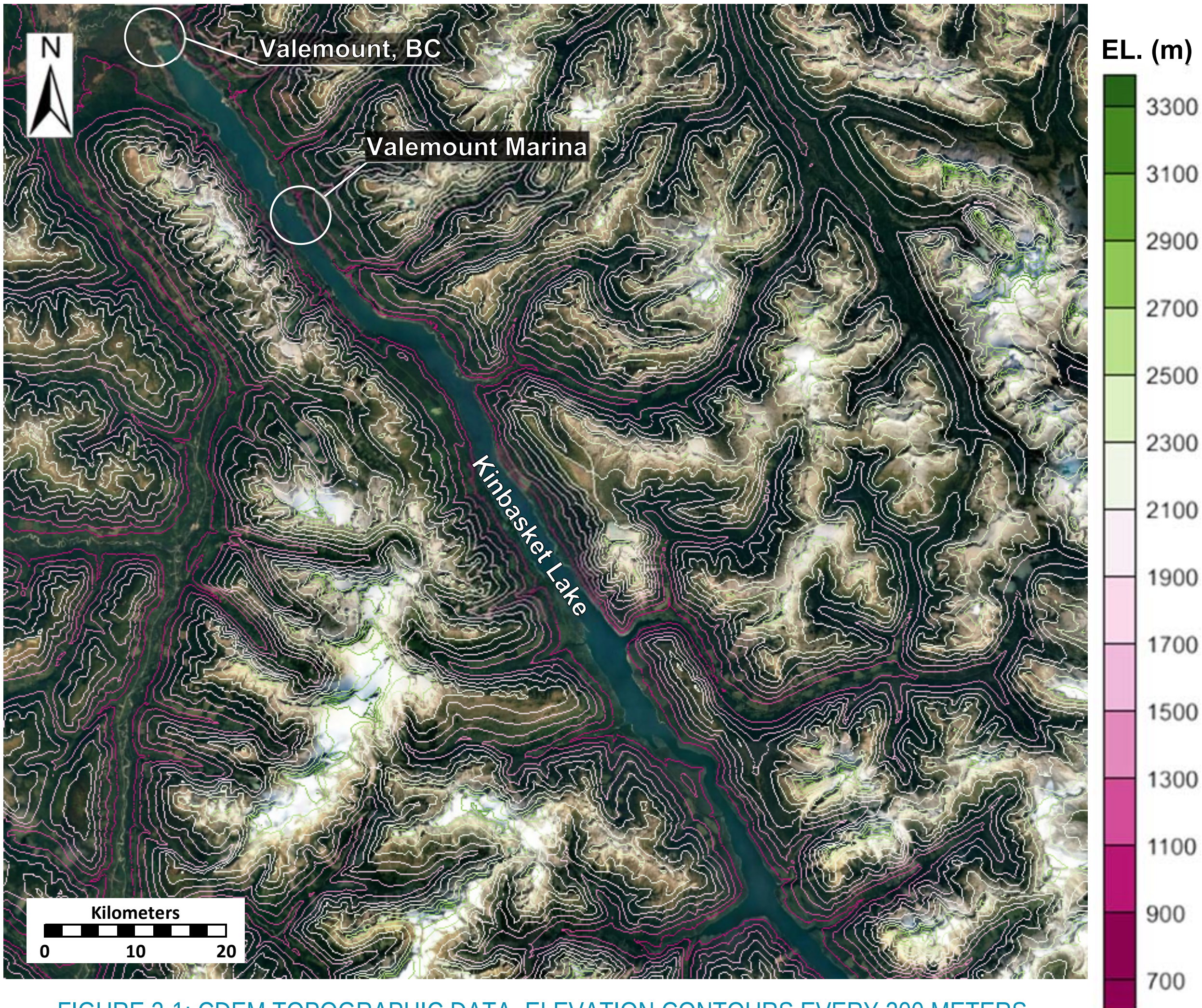

FIGURE 2-1: CDEM TOPOGRAPHIC DATA, ELEVATION CONTOURS EVERY 200 METERS.

The lake bathymetry was assembled based on topographic and bathymetric data for North Canoe Reach *(BCH, 2003)* and site surveys at Valemount Marina conducted by Atek Hydrographic Surveys Ltd. *(Atek, 2007, 2008)*. Figure 2-4 provides elevation contours for North Canoe Reach, while Figure 2-5 shows water depths and elevations in the area of Valemount Marina. In these figures, elevations below lake levels of 753 m indicate contours below water and are shown as blue. The shoreline is indicated with yellow. Above-water elevations are shown in green with higher elevations transitioning through brown.

2.2. Areas of Bed Level Change

M&N evaluated changes in lakebed and terrain elevations by comparing data from surveys conducted by *Atek (2007)* and *Atek (2008)*. In areas where the two surveys overlapped the 2007 elevation data was subtracted from the 2008 data to identify changes in elevation.

Figure 2-6 shows the changes between 2007 and 2008. Areas of erosion or where elevations decreased are indicated with red, while areas of accretion or elevation increase are highlighted in blue. Outline elevation contours, the marina access road, and the boat launch ramp are shown for reference.

The figure shows that areas affected by erosion and pronounced elevation changes are along the rock slope of the breakwater and the rock slope along the marina access road.

A new site survey was conducted in May 2018 to determine if the damage is progressive or if the material placed on the slopes has stabilized. Figure 2-7 shows elevation differences between the 2008 and 2018 surveys. The data indicates that the crest of the bank along the access road may have been subject to some erosion or slumping of the shore protection material. Another area of erosion or lowering of the lakebed elevation is at the toe of the launch ramp. It also appears that material has eroded or slumped around the tip of the breakwater. The recent survey shows other areas as having raised grades, which could be due to siltation or differences in survey techniques.

2.3. Wind Statistics

Wind data from the Howard Creek weather station was selected as representative of wind blowing over the lake. The station is located at (latitude: 52.3721°N, longitude: 118.6594°W). The location is marked in Figure 1-2.

Figure 2-2 shows wind speeds recorded at this weather station from 2005 to 2017.

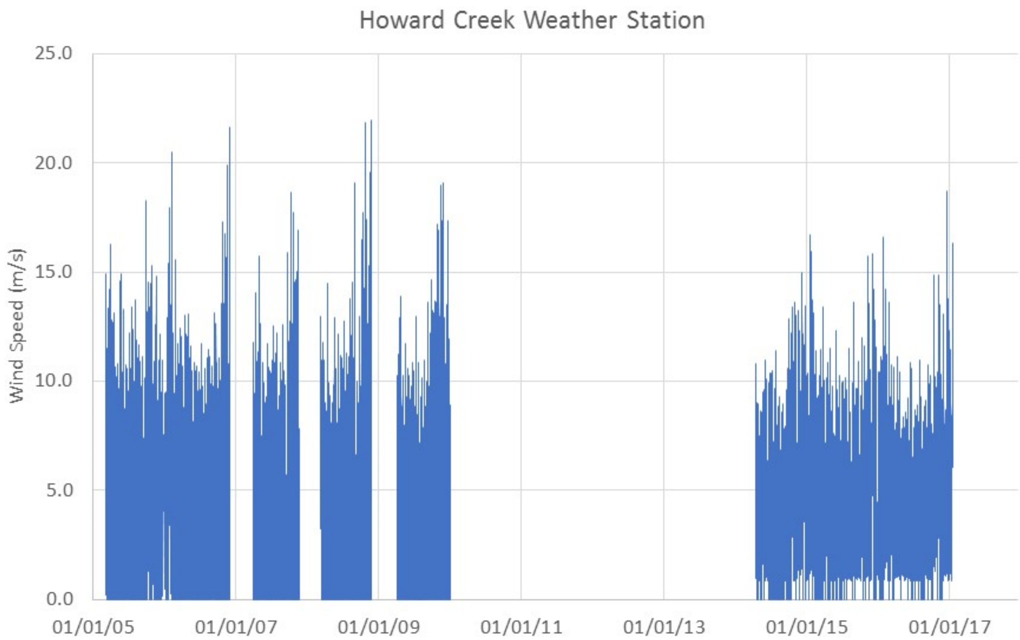

FIGURE 2-2: WIND DATA COVERAGE.

Wind limits for recreational craft usually follow the categorization of safe boater weather warnings shown in Table 2-1.

TABLE 2-1: SAFE BOATER WEATHER WARNINGS

Wind Category	Wind Speeds (knots)	Wind Speeds (m/s)	Warning
Light Winds	1 - 14	1 - 7	None
Moderate Winds	15 - 19	8 - 10	
Strong Winds	20 - 33	11 - 17	Small Craft Warning
Gale	34 - 47	18 - 24	Gale Warning
Storm	48 - 63	25 - 32	Storm Warning

Table 2-2 shows the percent occurrence of wind speeds by month. The percentage totals are summarized on the right side and the bottom row of the table.

The row outlined with a green box shows that the weather is calm 8.5% of the time. The percentages outlined by the orange box shows that wind speeds exceeding 11 m/s are relatively infrequent. A small craft warning to boaters is issued when winds are in the range from 11 to 17 m/s. A gale warning is issued when forecast wind speeds exceed 18 m/s.

The bottom rows of Table 2-2 show how many days of navigable weather for recreational boating occurs each month out of a year on average, and also how many hours when a small craft warning or gale warning would be in place each month. The hours are cumulative, and so 1 to 4 hours could indicate just one warning, and a higher number of hours could mean multiple instances of warnings issued. The data indicates that issuances of weather warnings for small craft would occur multiple times over the fall and winter months. In particular, there is a big jump from 7 hours on average in September, to 45 hours on average in October. This means that the shoulder season in late September is highly variable as there is a higher risk of encountering inclement weather, i.e. some years will be remembered as having nice weather in September, and other years will be remembered as having bad weather. It's a different situation during the early shoulder season beginning in June. At this point in time, potential small craft warning issuances have petered out (from 46 hours in January down to just 1 hour in June), and there is little risk of exposure to high wind events. In the month of May leading up to the shoulder season starting in June, the potential for small craft warnings is also low (4 hours) and there is therefore more certainty about nice weather when the early shoulder season starts.

The darker yellow area circled in black shows that mild winds from 1 to 5 metres per second occur more frequently over the summer months starting in April, but mainly May through August, into September.

TABLE 2-2: DISTRIBUTION OF WIND SPEEDS BY MONTH FROM JANUARY THROUGH DECEMBER.

Wind Speed (m/s)	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Calm	0.05	0.21	0.41	0.59	0.92	1.14	1.05	1.20	1.27	0.94	0.46	0.27	8.50%
0 - 1	0.06	0.07	0.16	0.32	0.44	0.44	0.45	0.51	0.46	0.32	0.15	0.07	3.47%
1 - 2	0.38	0.31	0.47	0.70	1.15	1.31	1.50	1.30	1.10	0.80	0.53	0.52	10.09%
2 - 3	0.40	0.35	0.63	1.14	1.60	1.78	1.92	1.91	1.52	1.24	0.86	0.62	13.96%
3 - 4	0.31	0.31	0.84	1.26	1.83	1.95	1.89	1.91	1.42	1.16	0.77	0.58	14.24%
4 - 5	0.35	0.32	0.70	1.37	1.78	1.40	1.56	1.35	1.35	1.15	0.76	0.61	12.69%
5 - 6	0.42	0.37	0.71	1.24	1.14	0.90	0.93	0.79	0.96	0.88	0.83	0.54	9.73%
6 - 7	0.40	0.44	0.65	1.12	0.83	0.68	0.63	0.68	0.84	0.90	0.97	0.64	8.76%
7 - 8	0.40	0.34	0.46	0.69	0.55	0.36	0.32	0.43	0.61	0.80	0.89	0.56	6.41%
8 - 9	0.32	0.22	0.36	0.50	0.27	0.24	0.21	0.27	0.40	0.63	0.76	0.46	4.65%
9 - 10	0.23	0.13	0.26	0.27	0.14	0.13	0.11	0.14	0.24	0.46	0.51	0.30	2.93%
10 - 11	[illegible]	[illegible]	.13	0.18	0.06	0.06	0.05	0.07	0.13	0.31	0.36	0.19	1.82%
11 - 12	[illegible]	[illegible]	.04	0.06	0.03	0.01	0.03	0.04	0.03	0.22	0.27	0.13	1.03%
12 - 13	0.05	0.01	0.03	0.04	0.02	0.00	0.01	0.00	0.03	0.16	0.24	0.08	0.69%
13 - 14	0.03	0.01	0.01	0.02	0.00	0.00	0.00	0.01	0.02	0.11	0.16	0.03	0.41%
14 - 15	0.02	0.01	0.01	0.01	0.00			0.00	0.01	0.07	0.14	0.01	0.27%
15 - 16	0.01	0.00							0.01	0.04	0.08	0.01	0.15%
16 - 17	0.01							0.00	0.00	0.01	0.05		0.08%
17 - 18	[illegible]	[illegible]						0.00	0.00	0.02	0.03	0.00	0.06%
18 - 19		[illegible]							0.00	0.00	0.02	0.01	0.03%
19 - 20		0.00						0.00		0.00	0.01		0.02%
20 - 21		0.00								0.00	0.00		0.01%
21 - 22										0.00	0.00		0.01%
22 - 23													0.00%
Total	3.8%	3.3%	5.9%	9.5%	10.8%	10.4%	10.7%	10.6%	10.4%	10.2%	8.8%	5.6%	100%
Navigable Weather	29	27	31	30	31	30	31	31	30	29	27	30	days
Small Craft Warning	46	22	11	10	4	1	3	4	7	45	79	35	hours
Gale Warning	0	1	0	0	0	0	0	0	0	1	3	1	hours

Small Craft Warning

Gale Warning

Less frequent, high-wind events (2.76% of the time in a year)

2.4. Lake Levels

Figure 2-3 summarizes historical lake level variations from 1984 to 2015. The annual lake level variation is indicated by the grey curves. Water is drawn from the lake (reservoir) year-round and is recharged with water from snowmelt over the months from May through August.

The envelope of maximum and minimum lake levels are indicated by the green and red curves, respectively. The maximum lake level is around 754.5 metres and the minimum around 712 metres. Percentiles of 10%, 50%, and 90% are indicated by the orange, yellow, and green curves.

The boat launch ramp at Valemount Marina extends from approximately elevation 728 m to 755 m and provides access to the lake 83% of the time over the year. Based on historical lake levels, the lake is accessible all of the time during the peak boating season from June 15 to September 14. The lake is accessible 92% of the time during the shoulder season from June 1-14 and from September 15-30.

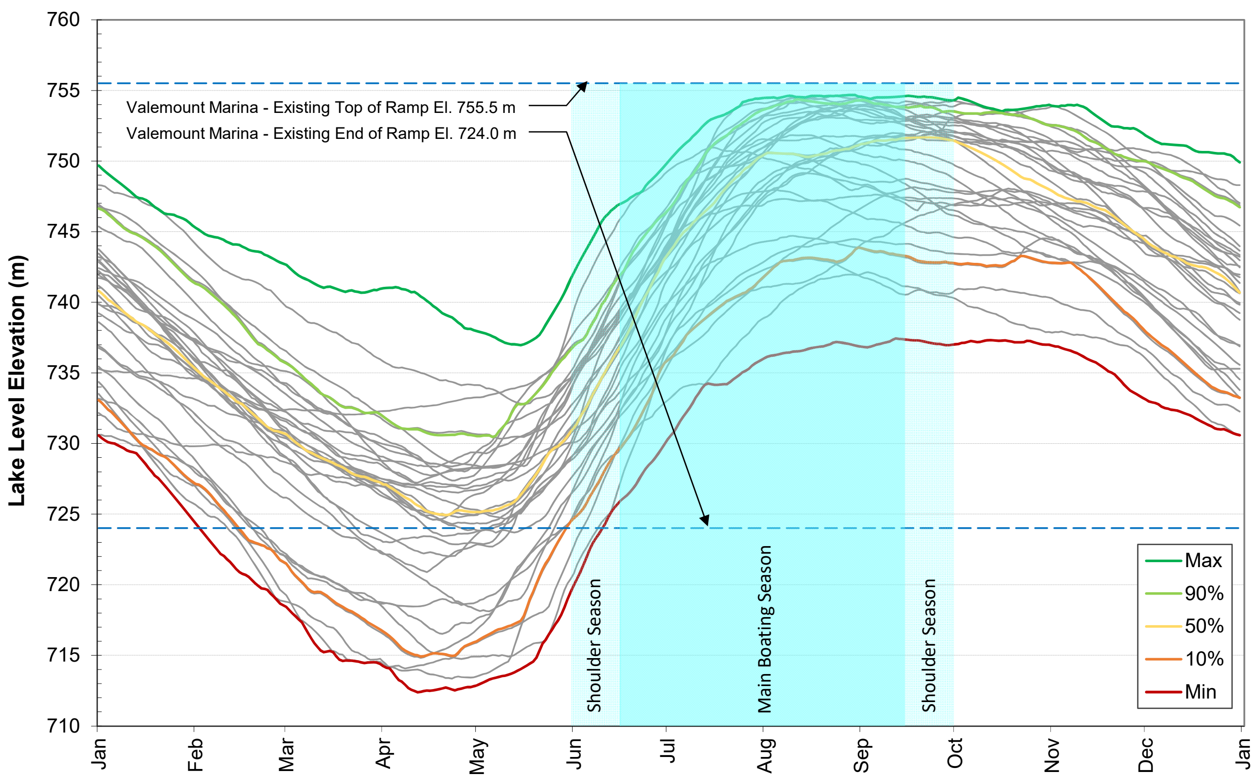

FIGURE 2-3: KINBASKET LAKE HISTORICAL WATER LEVEL ELEVATIONS 1984 – 2015.

Table 2-3 provides an overview of the average lake level and maximum wind speeds that can occur over the months of the shoulder season and main boating season.

TABLE 2-3: OVERVIEW OF LAKE LEVELS AND WIND SPEEDS DURING BOATING SEASON.

Dates	Period	Lake Level (m)	Maximum Wind Speed (m/s) From	
			Northwest	Southeast
June 1st	Shoulder Season	724.0 to 728.0	7.6	10.6
Early June		728.0 to 734.2	8.6	13.3
Mid June	Main Boating Season	734.7 to 736.2	10.7	11.7
Late June		736.6 to 743.1	10.0	10.7
July		743.4 to 750.3	13.4	12.4
August		750.3 to 751.1	11.9	11.6
Early September		751.2 to 751.5	13.1	9.8
Late September	Shoulder Season	751.5 to 753.5	10.9	14.5

2.5. Wind Conditions for Landing

Prior to extension of the boat launch ramp, the ramp was aligned approximately parallel to the road along the lakeshore. In order to extend the launch ramp to a lower lake level and meet the grades required for usage, a turnout was incorporated and the lower portion of the ramp aligned approximately east-west. A ramp extension with a different alignment would not have been feasible as it would have been cost prohibitive (would have required extensive amounts of cut and fill), or would have resulted in other usage problems, i.e. the ramp would have been too long.

Appendix A provides figures that give an overview of the topography around the marina at varying lake levels. In the figures, the lake water level is indicated in blue, and the above water topography in shades of brown. The shoreline band is represented by the white stripe along the water's edge. The arrows indicate the primary wind directions, and the boat outline indicates ramp access at the waterline.

For lake levels in the range from 740 to 754 meters, boats come along parallel to shore (and the lakeshore road) when launching and landing on the ramp. Over the range of lake levels from 728 to 737 meters the ramp orientation is more east-west. These are the lake levels where there could be more beam wind exposure when users launch and land on the ramp. It can be noted that the breakwater forms a promontory at these lower lake levels which provides a good amount of shielding from southeasterly wind and waves. At lake levels below 730 meters, the toe of the launch ramp is situated in a little cove, which would provide partial shielding against both southeasterly and northwesterly winds. At lake levels between 730 and 737 meters, the waterbody around the ramp opens up, and it is likely under these conditions that users have reported a heightened wind exposure.

In conclusion, it appears that the rubble-mound breakwater provides adequate protection for wind from southeasterly directions, and it is likely northwest winds that affect users when accessing the launch ramp.

Conditions for launching and landing are to a certain extent dependent on the experience of the users. *PIANC (2016)* guidelines for recreational boating provides guidance in terms of threshold limits for safe navigation. For navigation areas exposed to crosswinds, as might be the case when the lake level is low and the accessible ramp portion has an east-west alignment, mild conditions are characterized by wind speeds below 7.7 meters per second (15 knots).

Another approach is to look at wind-driven crosscurrents where PIANC (2016) guidelines categorize mild conditions as being within the range from 0.10 to 0.26 meters per second (current speed of 0.2-0.5 knots). The maximum speed of wind-driven currents typically reaches about 3% of the wind speed. The limiting wind speeds corresponding to the stated crosscurrent velocities are therefore in the range from 3.4 to 8.6 meters per second. The lower range can probably be said to apply to very sensitive boaters whereas the upper range would apply to more experienced boaters, but overall reflecting *mild* conditions.

Per the wind statistics summarized in Table 2-2, the upper wind speed threshold of 8.6 m/s is only exceeded a couple of days out of the shoulder season. Conversely, the low threshold of 3.4 m/s is exceeded for about 20 days (cumulatively) out of the shoulder season. In conclusion, the indication is that mild conditions persist for the majority of the time, but highly sensitive boaters may encounter difficult conditions more frequently and at times of northwesterly winds. A solution could be to advise boaters to avoid launching and landing during windy conditions.

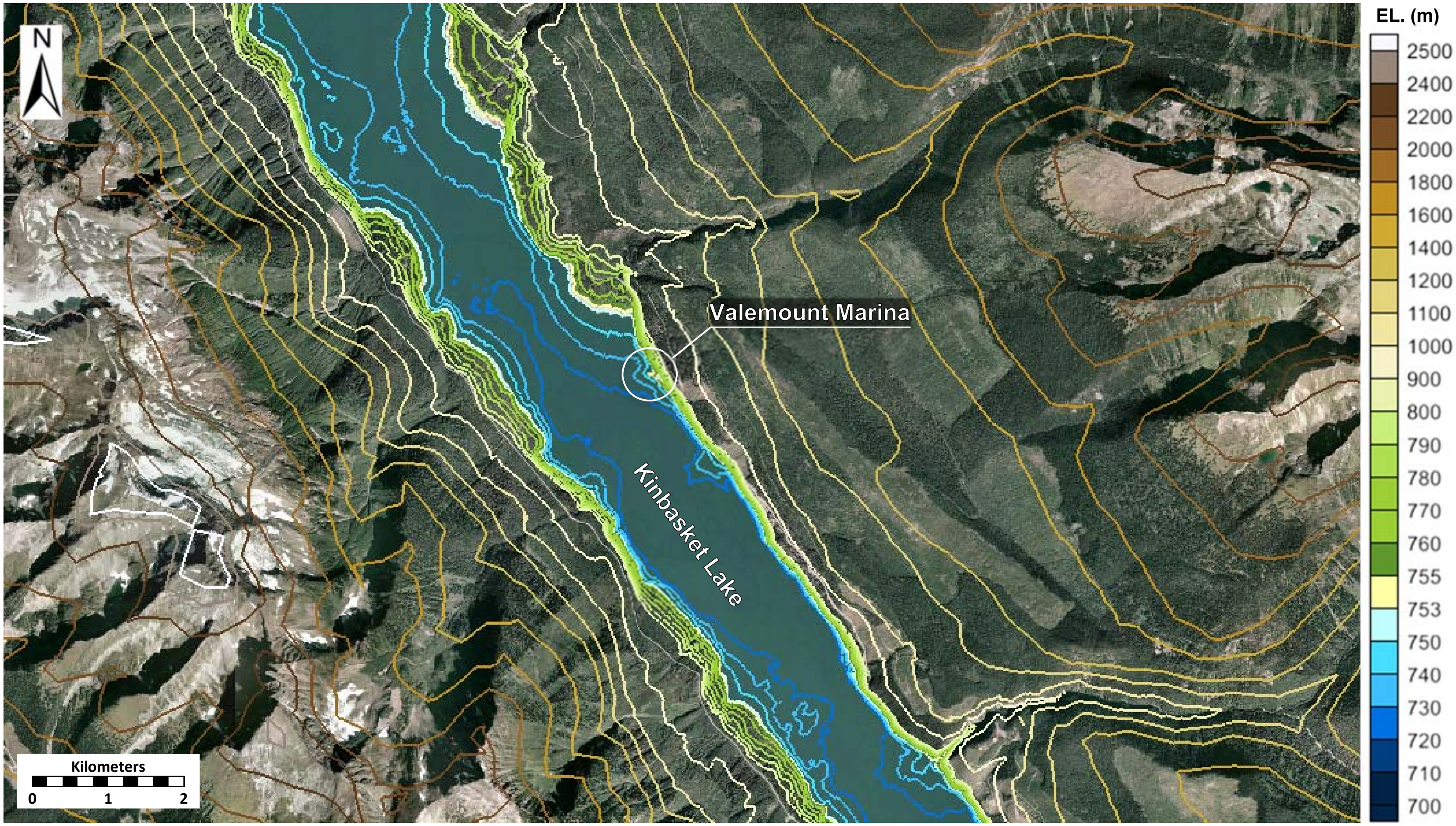

FIGURE 2-4: KINBASKET LAKE NORTH CANOE REACH TOPOGRAPHIC AND BATHYMETRIC DATA.

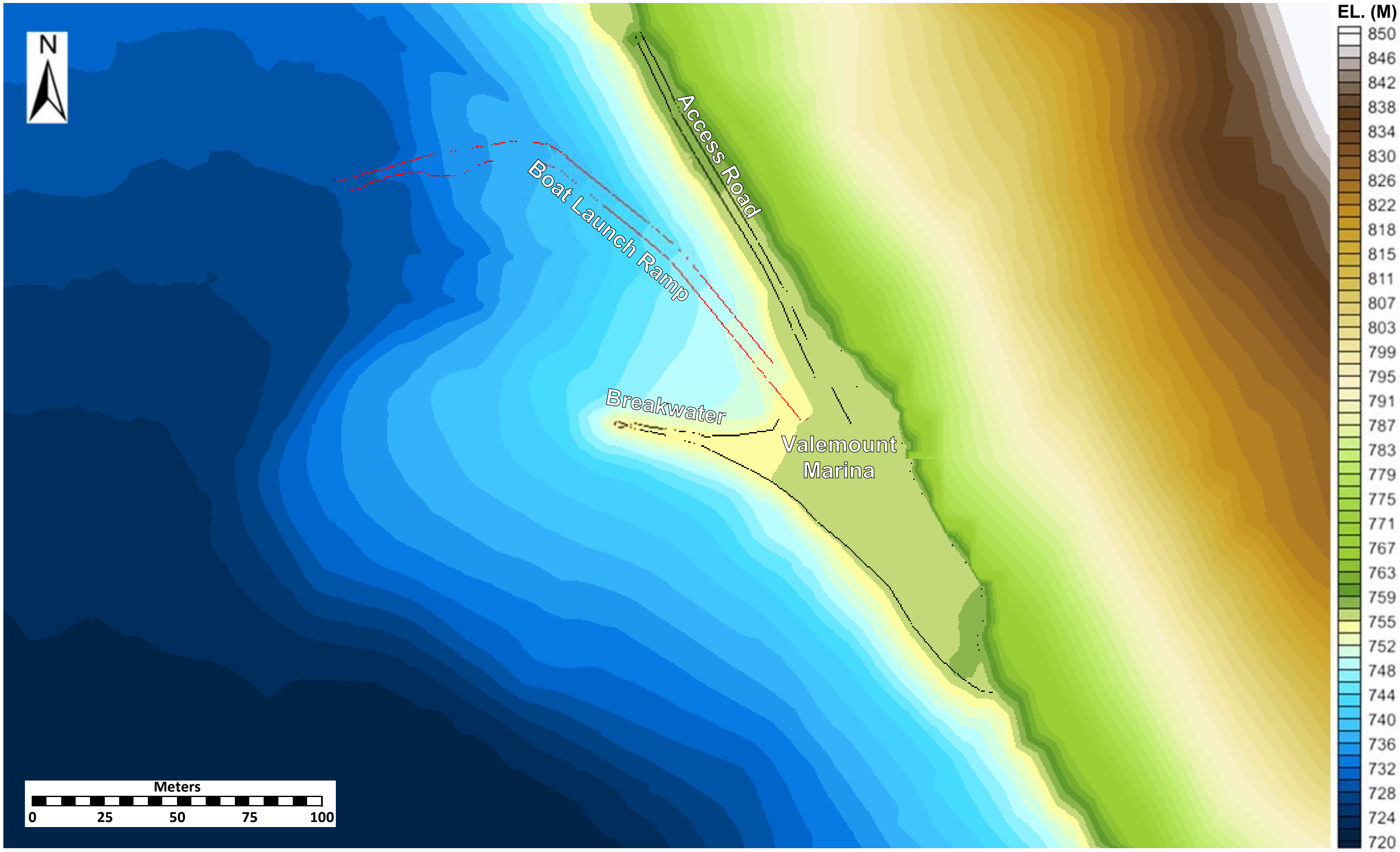

FIGURE 2-5: VALEMOUNT MARINA BATHYMETRIC AND TOPOGRAPHIC DATA, ELEVATION CONTOURS EVERY 2 METERS.

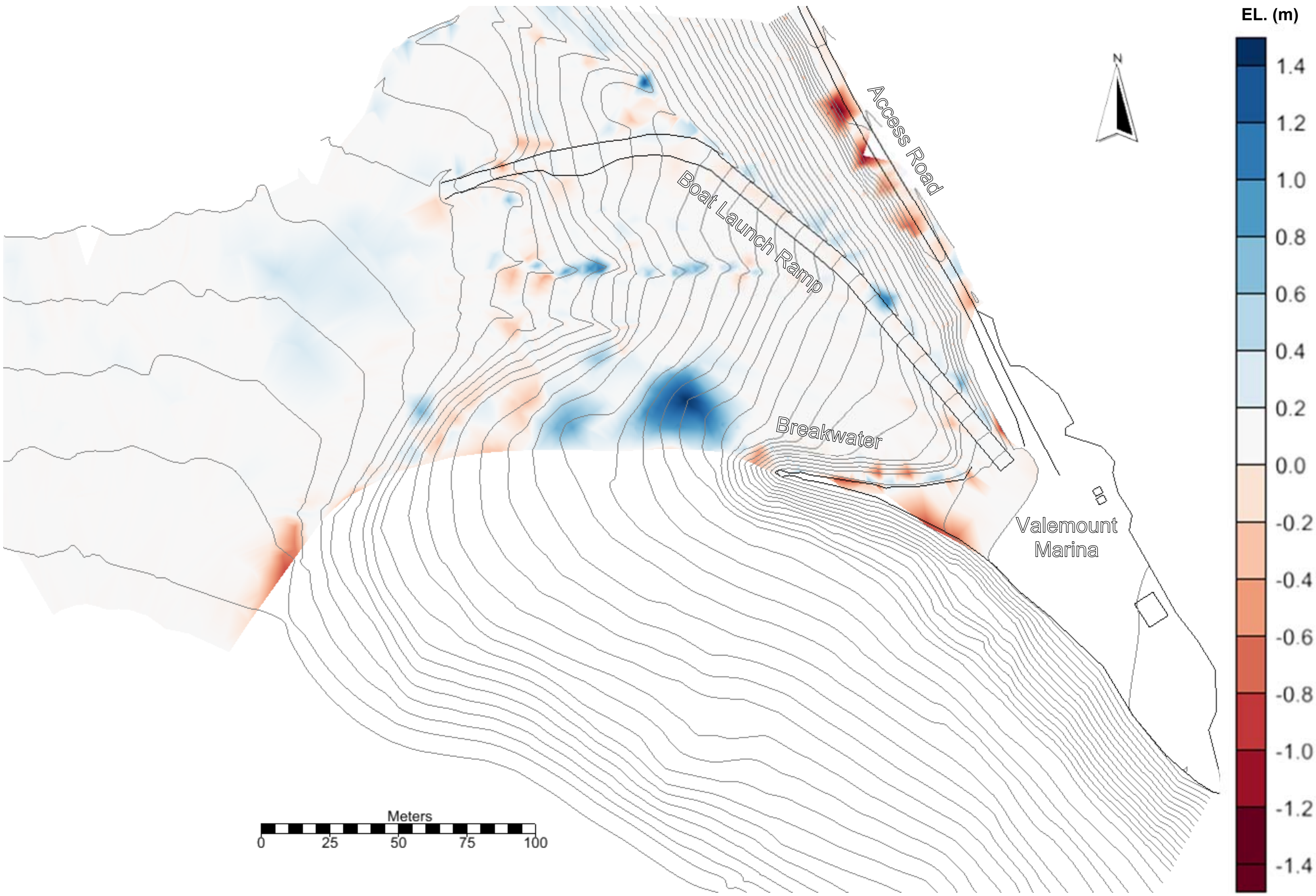

FIGURE 2-6: VALEMOUNT MARINA ELEVATION CHANGES BETWEEN ATEK 2007 AND 2008 SURVEYS.

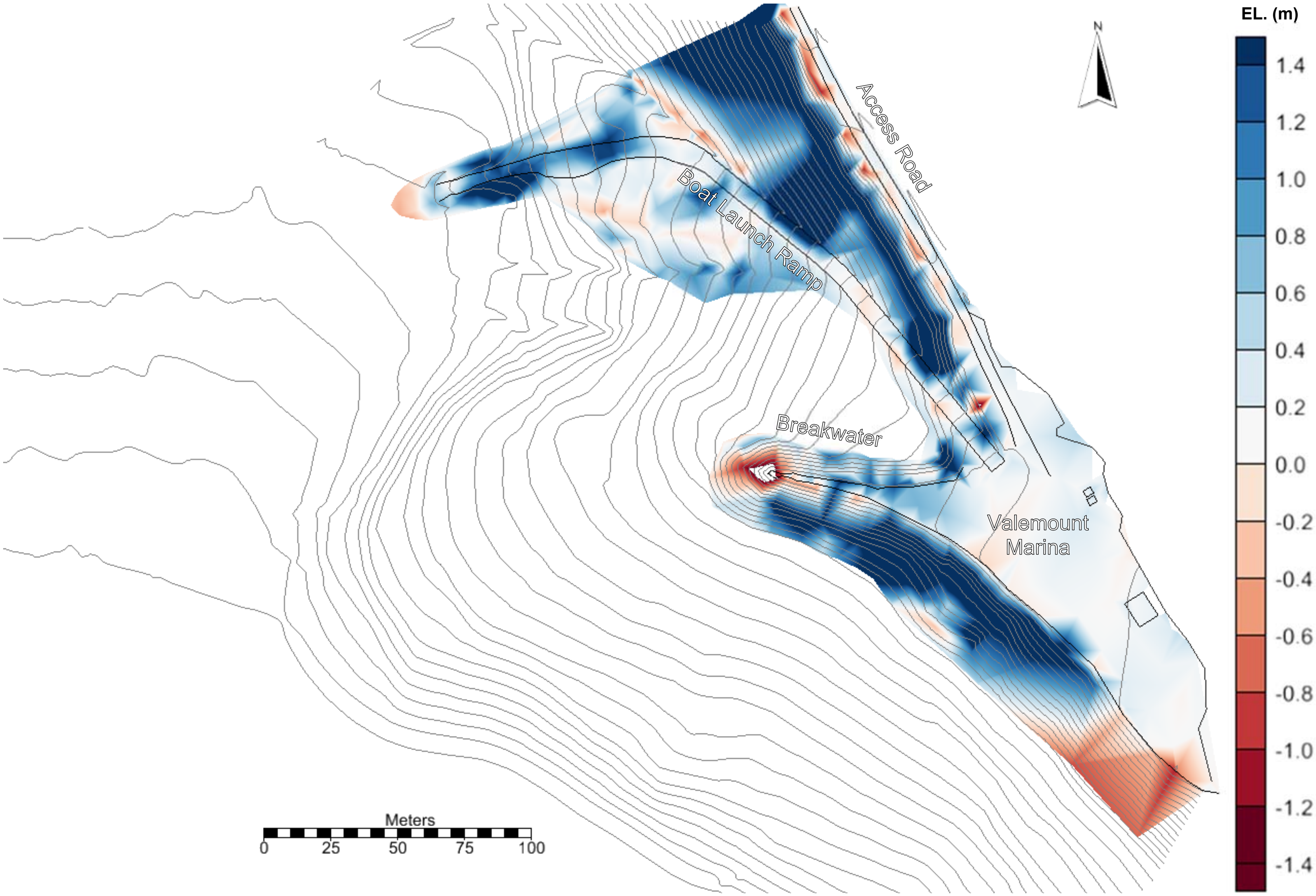

FIGURE 2-7: VALEMOUNT MARINA ELEVATION CHANGES BETWEEN ATEK (2008) AND MSG (2018) SURVEYS.

3. Wind-Wave Analysis

Topographic data, wind statistics, and lake level data was used to perform a Spectral Wave (SW) analysis for the Valemount Marina. The MIKE21 SW model was utilized to conduct this analysis. Two main wind conditions with a wind speed of 11 m/s were considered corresponding to a 1-year return period wind condition; northwesterly winds (320˚ true north), and southeasterly winds (140˚ true north).

Figure 3-1 and Figure 3-2 shows the wave analysis results at the marina and its neighbouring shoreline for northwesterly wind. The results show that for this condition significant wave heights[1)] range between 0.4 m and 0.6 m around the breakwater, and inside the marina.

Peak wave periods are in the range from 2.7 to 3.1 seconds[2)]. The solid black line in these figures depicts the docks, and the dotted black line outlines the existing kayak launch ramp. At times of northwesterly wind, the marina is directly exposed to waves and the floats are therefore aligned with this direction so that waves are incident head-on.

Figure 3-3 and Figure 3-4 shows the wave analysis results at the marina and its neighbouring shoreline for southeasterly wind. The results show that for this condition significant wave heights range between 0.5 m to 0.6 m on the outer side of the breakwater, with peak periods in the range from 2.7 to 3.3 seconds. As shown in Figure 3-3, the marina is sheltered from wave action at times of southeasterly wind and waves and significant wave heights within the marina are below 0.2 m.

From the results of the wave analysis, it is clear that the outer side of the breakwater is subject to wave action during both southeasterly and northwesterly waves, with slightly larger waves generated from southeast winds.

Wave analysis results for varying lake levels are provided in Appendix A and summarized in Table 3-1.

[1] The significant wave height is defined as the average of the highest one-third of the waves. The largest waves can be approximately two times the significant wave height. The wave height is defined as the distance from the wave trough to the crest of a wave.
[2] The peak wave period is defined as the wave period associated with the most energetic waves in the total wave spectrum.

TABLE 3-1: WAVE HEIGHT VARIATION DURING BOATING SEASON.

Dates	Period	Lake Level (m)	Significant Wave Height (m) at Ramp for Wind From	
			Northwest	Southeast
June 1st	Shoulder Season	724.0 to 728.0	0.05	0.10
Early June		728.0 to 734.2	0.10	0.10
Mid June	Main Boating Season	734.7 to 736.2	0.15	0.10
Late June		736.6 to 743.1	0.25	0.10
July		743.4 to 750.3	0.40	0.05
August		750.3 to 751.1	0.42	0.05
Early September		751.2 to 751.5	0.45	0.05
Late September	Shoulder Season	751.5 to 753.5	0.45	0.05

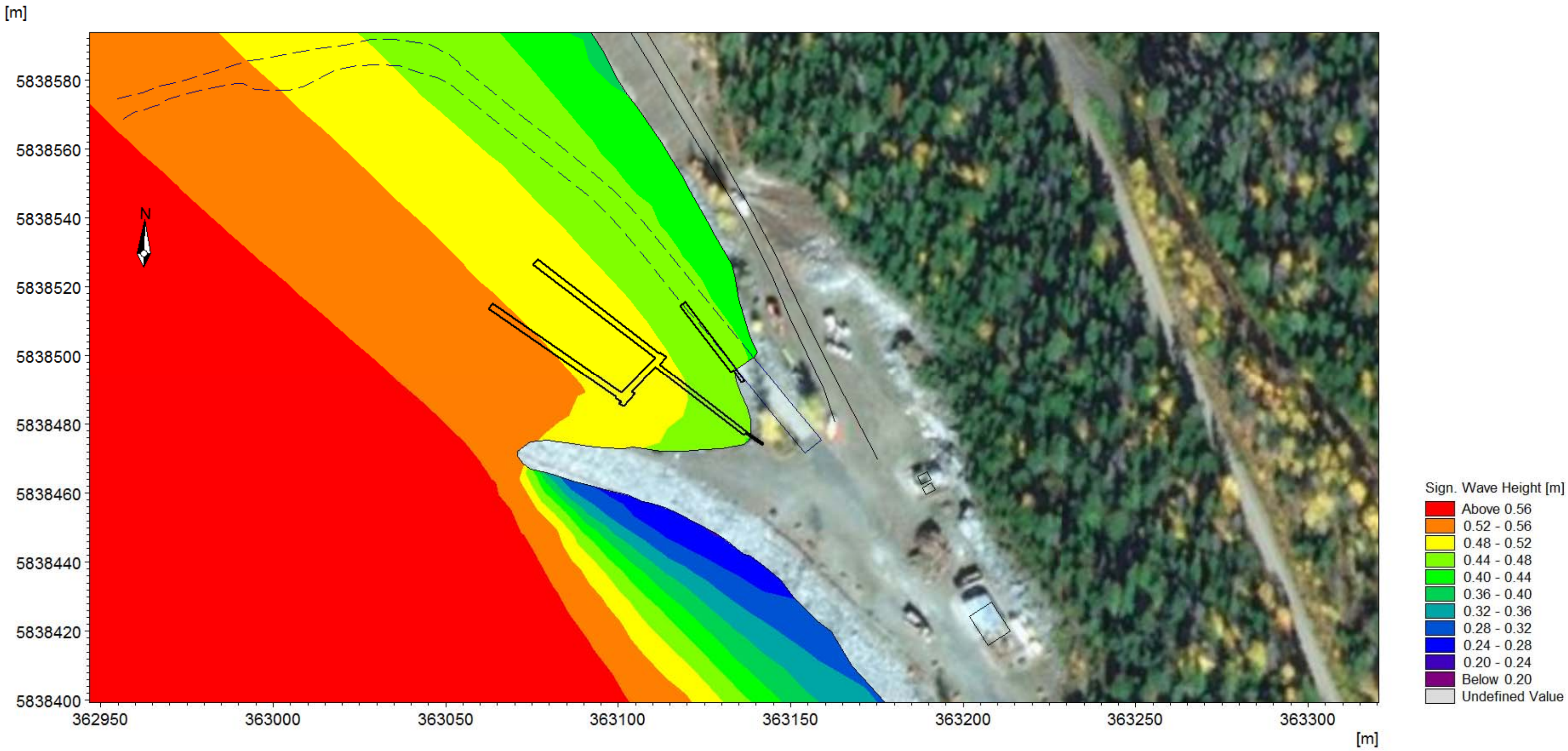

FIGURE 3-1: SIGNIFICANT WAVE HEIGHT VARIATION FOR NORTHWESTERLY WINDS.

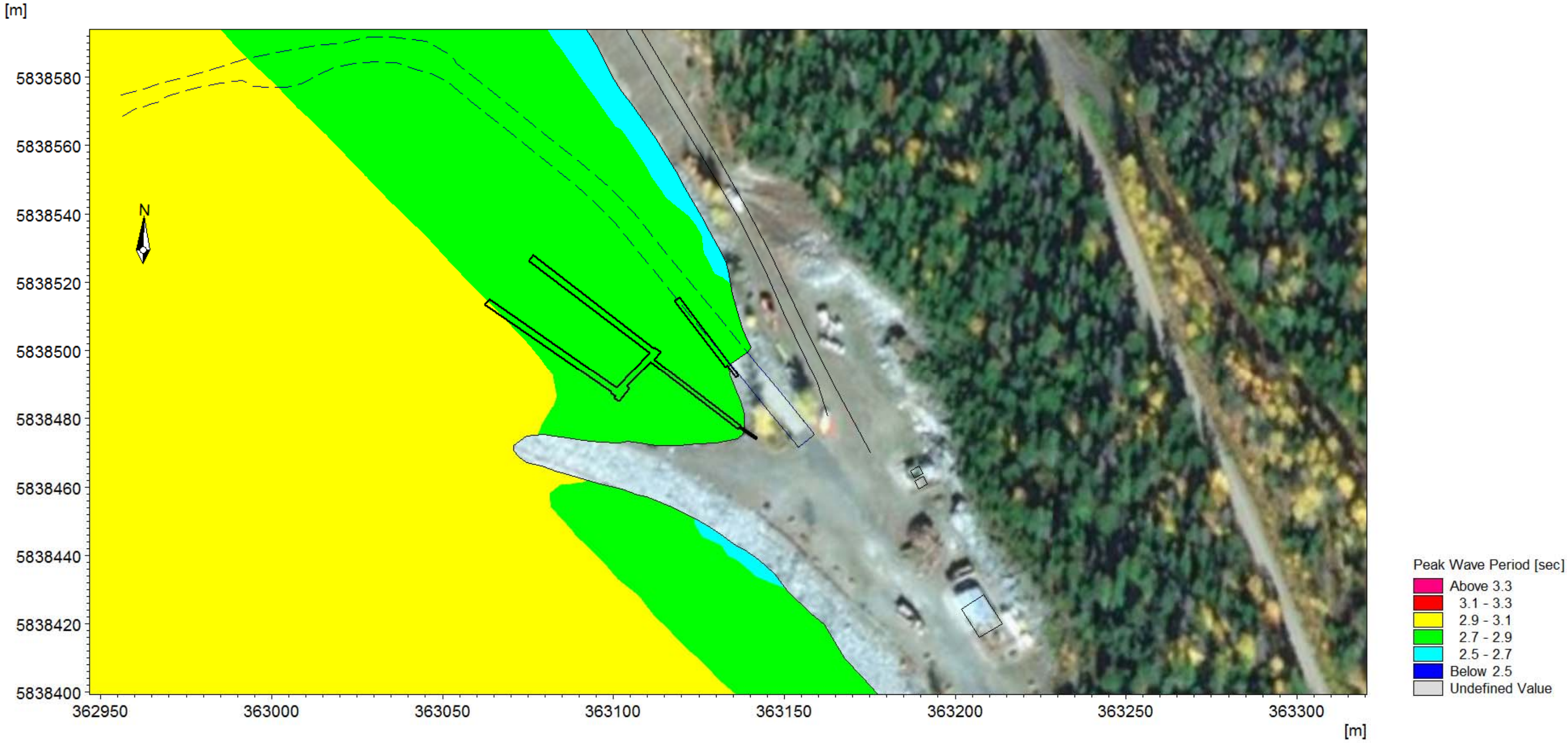

FIGURE 3-2: PEAK WAVE PERIODS ASSOCIATED WITH NORTHWESTERLY WINDS.

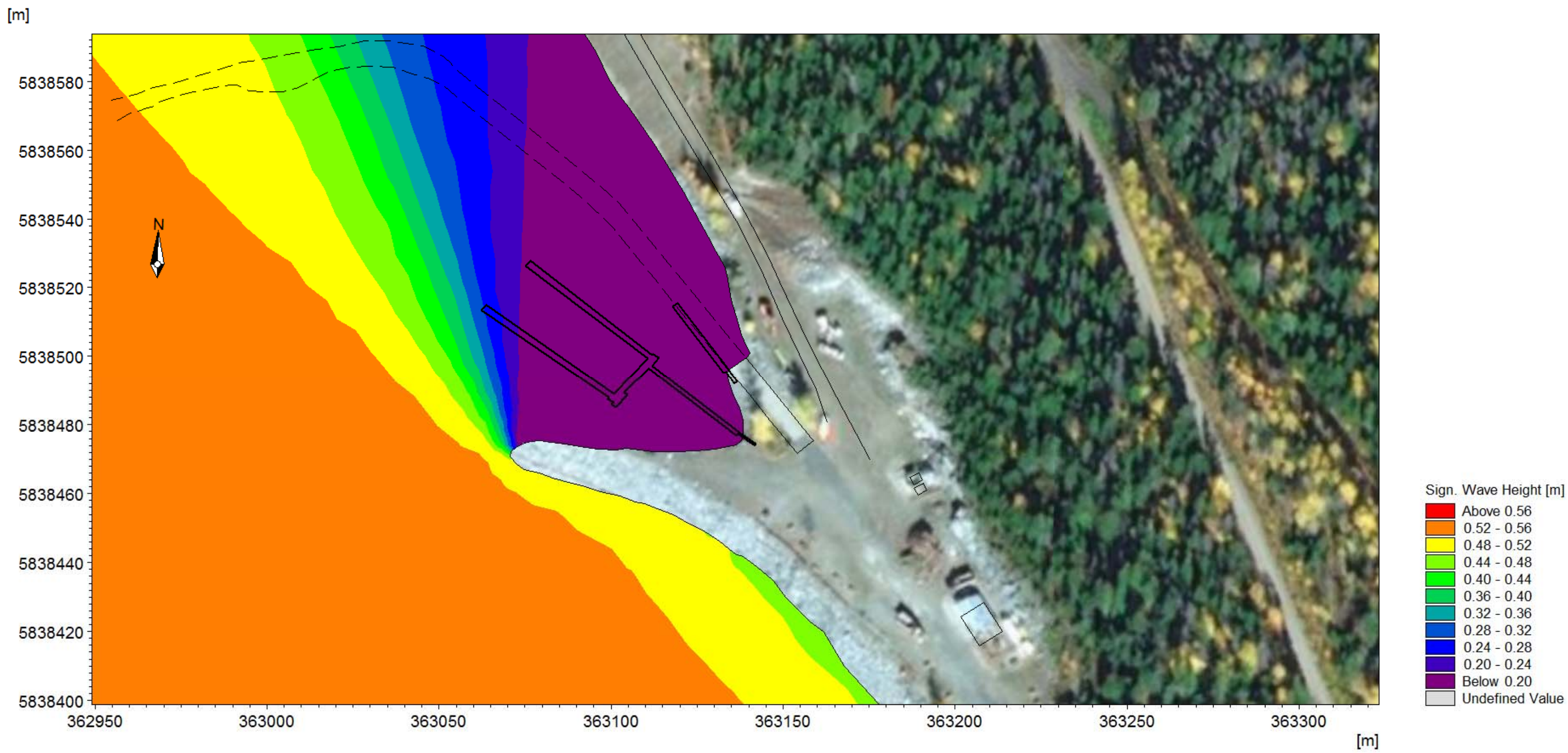

FIGURE 3-3: SIGNIFICANT WAVE HEIGHT VARIATION FOR SOUTHEASTERLY WINDS.

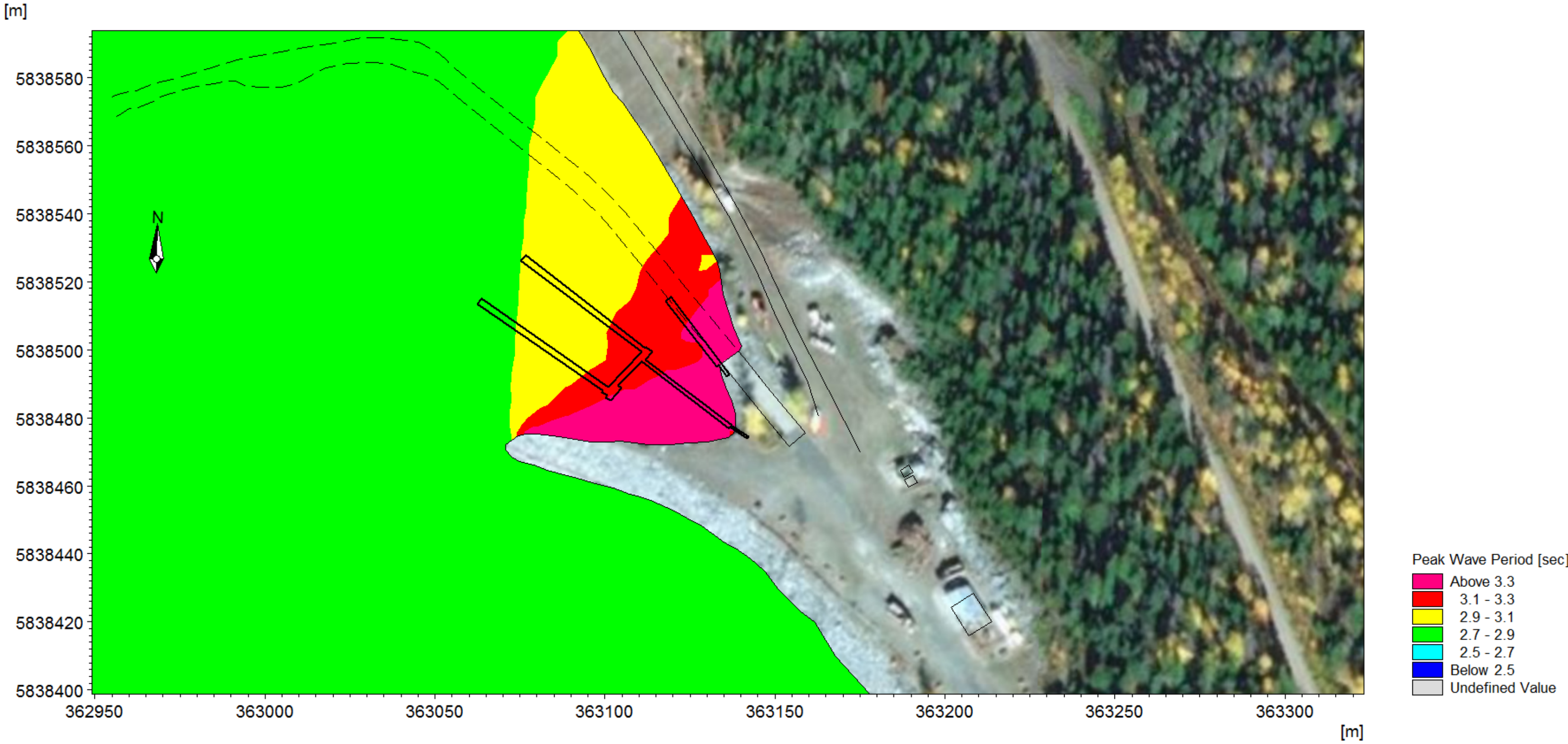

FIGURE 3-4: PEAK WAVE PERIODS ASSOCIATED WITH SOUTHEASTERLY WINDS.

4. Summary of Findings

4.1. Wind Conditions for Launching and Landing

In conclusion, it appears that the rubble-mound breakwater provides adequate protection for wind from southeasterly directions, and it is likely northwest winds that affect users when accessing the launch ramp.

The indication is that mild conditions persist for the majority of the time, but highly sensitive boaters may encounter difficult conditions more frequently and at times of northwesterly winds.

The present study estimates that times when conditions for landing are untenable, could be on the order of a few hours out of the shoulder season up to 5 days of time cumulatively for boaters requiring ideal conditions for launching and landing.

A solution could be to advise boaters to avoid launching and landing during windy conditions.

If landing is related to both wind and wave conditions, a log boom or floating wave attenuator could be incorporated to shield the ramp from waves developing over the lake. A simple mooring system could be utilized to keep the wave attenuator in position alongside the ramp, enabling it to move vertically with changes in lake level. Another solution could be to upgrade the lower ramp with a rail-mounted pontoon, which would enable users to come alongside a boarding float when launching and landing at the ramp.

4.2. Rubble Mound Breakwater Erosion

Following construction of the marina extension, erosion was observed along the edge of the rubble mound breakwater. Atek was commissioned to conduct a site topographic and bathymetric survey in 2008, which was compared to the post-constructed site survey from 2007 (Figure 2-6). Areas of erosion were identified along the outside face of the rubble mound breakwater and along the inside face as well.

The areas where the breakwater profile was affected were all up near the crest of the breakwater around elevation 754.0. If the erosion was wave-related, it means that the damage is likely to have happened within the time span from August to November where the lake level is up around this elevation (ref. Figure 2-3).

The common behavior of placed rock that is unstable is that it will redistribute to a flatter slope which is stable. This can take place by a number of mechanisms, such as slumping, sliding, avalanching, slope failure, and wave-induced material transport. These are discussed briefly in the following:

1. Erosion due to wind-waves building up over the lake during high winds. This type of damage is commonly seen around the waterline. Wave-related erosion can occur if the slope protection material, or a substantial fraction of it, is undersized. The same situation could occur if the design wave parameters were underestimated (also resulting in the slope protection material being undersized). Also, if material of too large diameter is placed atop of fine material, the

finer material can leach out through the voids of the larger material when subjected to wave action. A comparison of the Atek (2007) and Atek (2008) survey data did indicate that some slopes had flattened, which could point to wave-induced erosion as the cause. However, because of differences between survey points and survey coverage, this finding is only indicative. In conclusion, if the breakwater had been constructed as designed, it should not have been subject to erosion.

2. Post-construction slumping of material due to incorrect placement or compaction. The stability of the placed slope protection material is closely tied to how steeply the material is placed relative to its natural angle of repose. For example, the steepest angle at which beach sand can be placed is around 28 to 32 degrees, but when subject to wave action the beach slope is much flatter at around 2 to 6 degrees. The best quality angular rock can achieve a natural angle of repose of up to 50 degrees, but if mixed with finer material or not stable due to wave action, will reorient to a flatter slope. Slumping can also occur if excess weight is imparted on the placed material. This can sometimes occur if construction equipment driving atop the placed material is too heavy. Slumping can typically be identified by one portion of the slope having lowered and having a bulge of material next to it. This pattern was not noticeable in the survey comparison, and slumping of the material is therefore not the likely cause of the erosion.
3. Segregation of material during placement, which means that some areas will be protected with larger-diameter rock, while the surface in other areas will be faced with material that is too small in diameter to withstand wave action. The typical pattern of erosion in this case is the finer material is removed or winnowed away. This leads to a type of failure where the slope material slides down the slope (avalanching). A comparison of the survey data reveals that this type of erosion may have occurred. Examination of post-construction photos support this finding.
4. Slope failure due to a decrease in lake level. This type of failure can occur if the slope material is saturated with water while the lake is subjected to a rapid drop in water level. The weight of the saturated soil can then cause the slopes to fail. The damage pattern associated with this type of failure is usually expressed as large circular slope failures. This type of slope failure is not observable in the survey data, and this type of failure mechanism is therefore not the cause of the erosion.
5. Localized rock slides due to users traversing the slopes or crest edges of the placed rock. As the damage observed is up around elevations near the crest of the breakwater, it cannot be ruled out that foot traffic could be an element of the observed erosion. It is however deemed unlikely to be the leading cause as it would be quite dangerous to mobilize rock sliding in this manner.

At this time, the indication is that the erosion may have been associated with the slope protection material being out of spec and not placed per the design requirements. This is supported by the indicative failure mechanisms observed, which include:

- Wave-induced erosion, supporting the fact that the placed material was undersized.

- Examination of post-construction photos, which indicate that portions of the material placed during construction may have been subject to segregation. This commonly happens if material is dumped at the top of the slope and rolls down, whereas the appropriate construction method is to build the slope starting at the toe and working up.
- Avalanching, which can cause material to slide down along the slope if portions of the slopes are eroded and/or if the material was placed too steeply.

The specific cause of the damage is not known in detail at this time. The present analysis therefore, evaluates wave action as the potential cause of the erosion.

BC Hydro commissioned a new site survey was conducted by Monashee Surveying and Geomatics on May 8, 2018. This latest survey points to the crest of the bank along the access road may as having been subject to erosion or slumping. Another area where the lakebed has lowered or been eroded is at the toe of the launch ramp. It also appears that material has eroded or slumped around the tip of the breakwater. Other areas appear to have raised grades, which could be due to siltation or due to differences in survey techniques. The latest survey data does not conclusively point to one cause or another but does not oppose the finding that the slope protection material may be affected by wave action.

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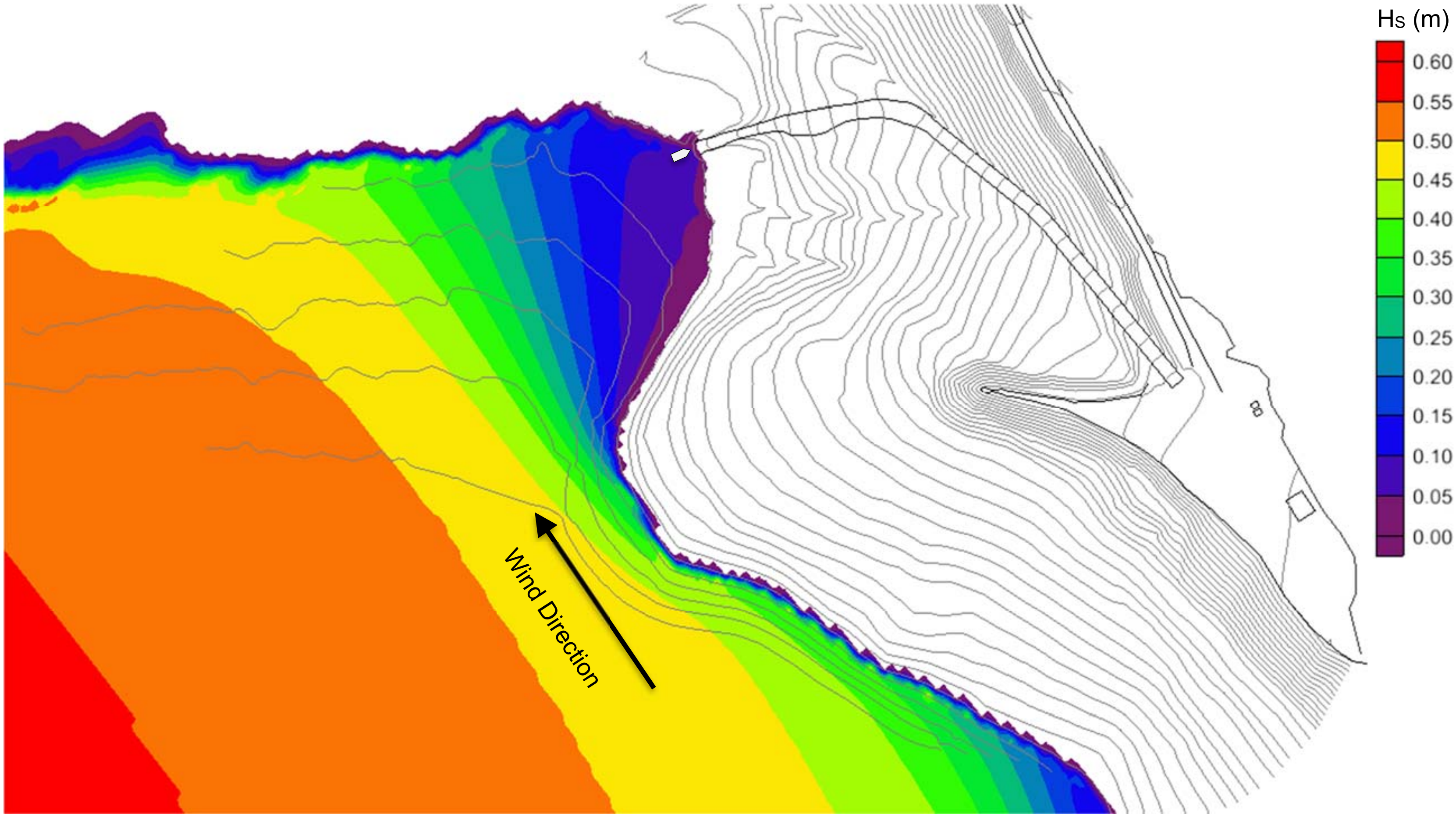
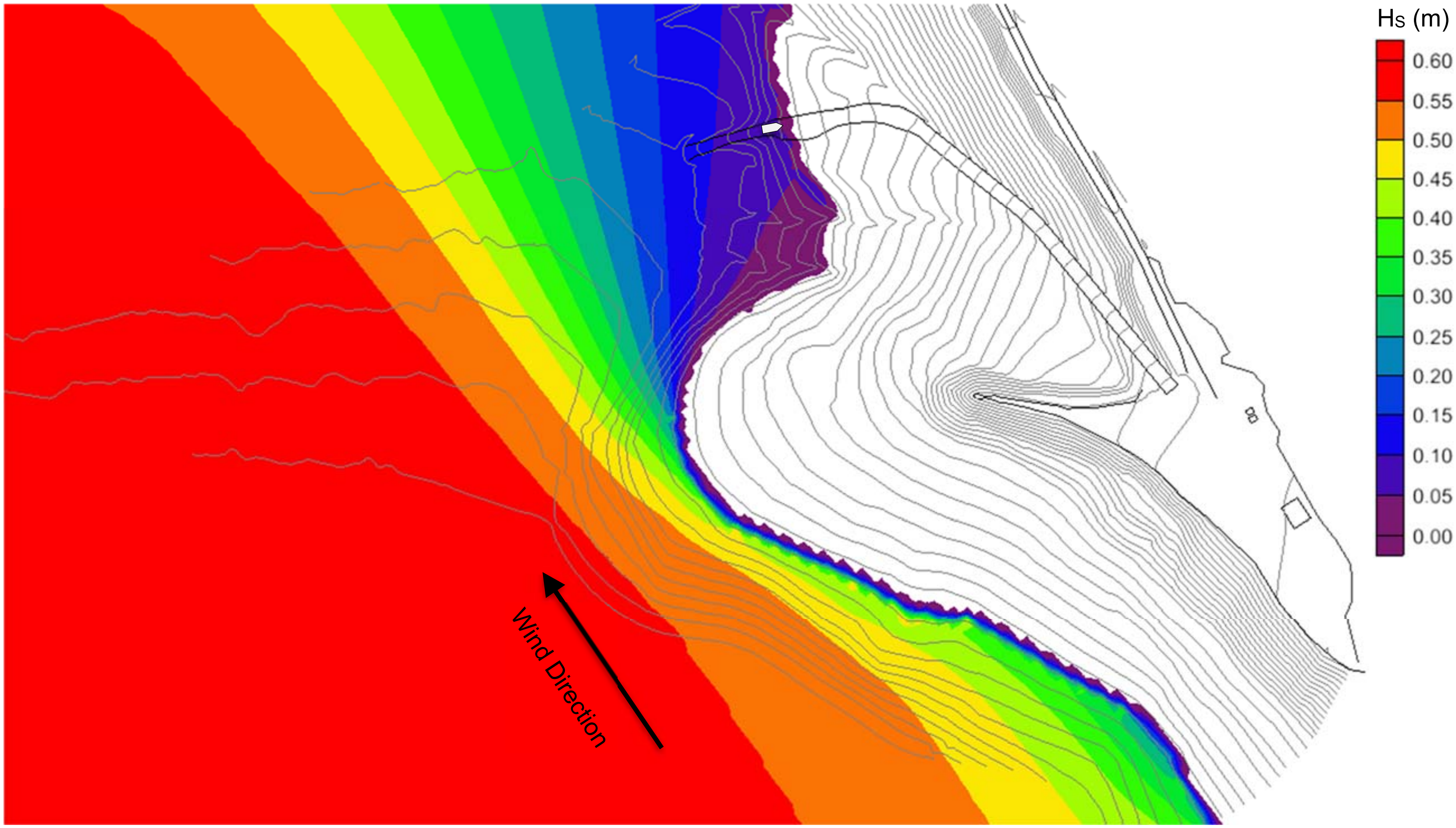
Appendix A:
Wave Exposure and Launch Ramp Access at Varying Lake Levels



SIGNIFICANT WAVE HEIGHT VARIATION AT LAKE LEVEL 728.0 METERS, START OF SHOULDER SEASON (JUNE 1).



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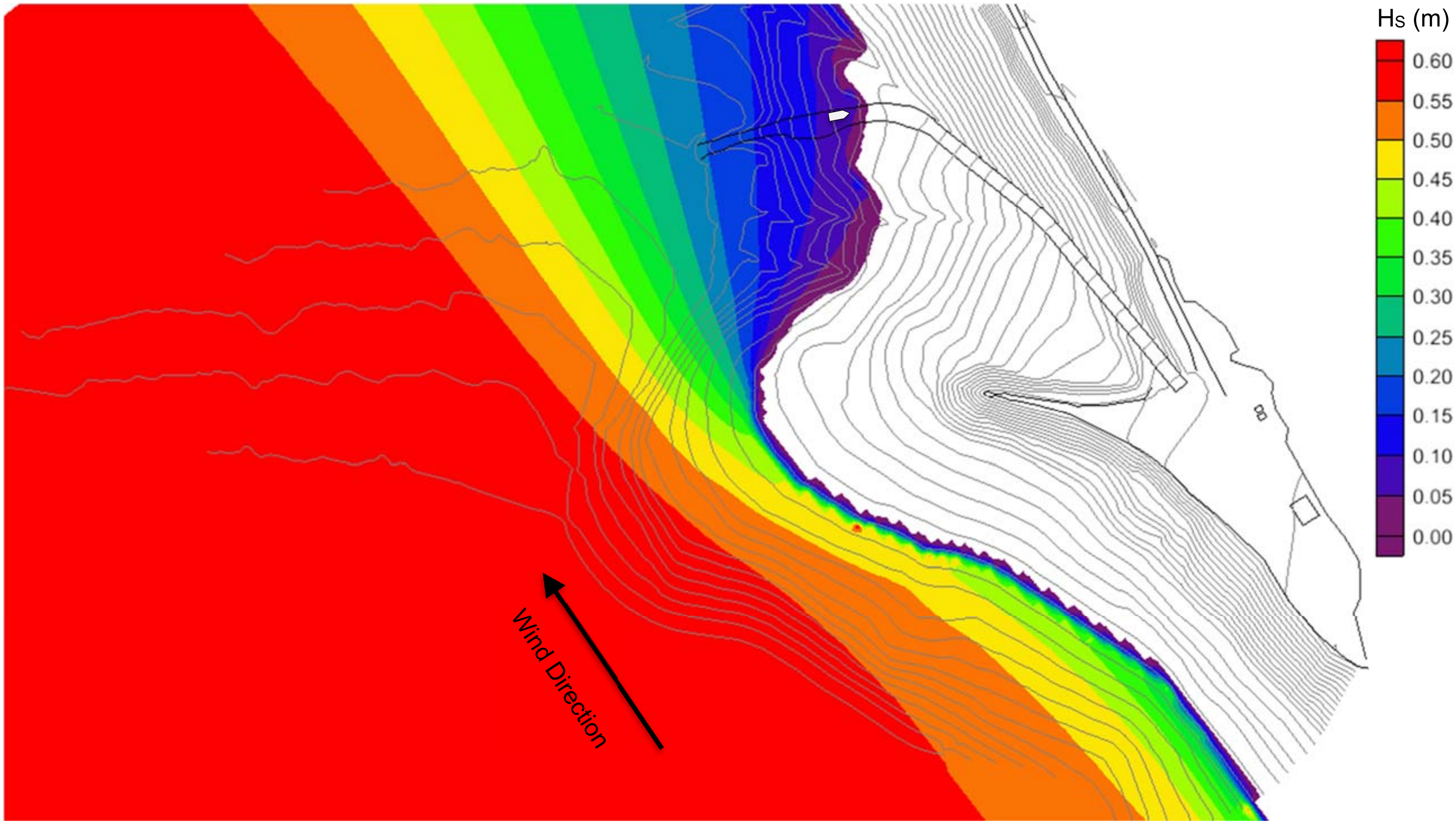

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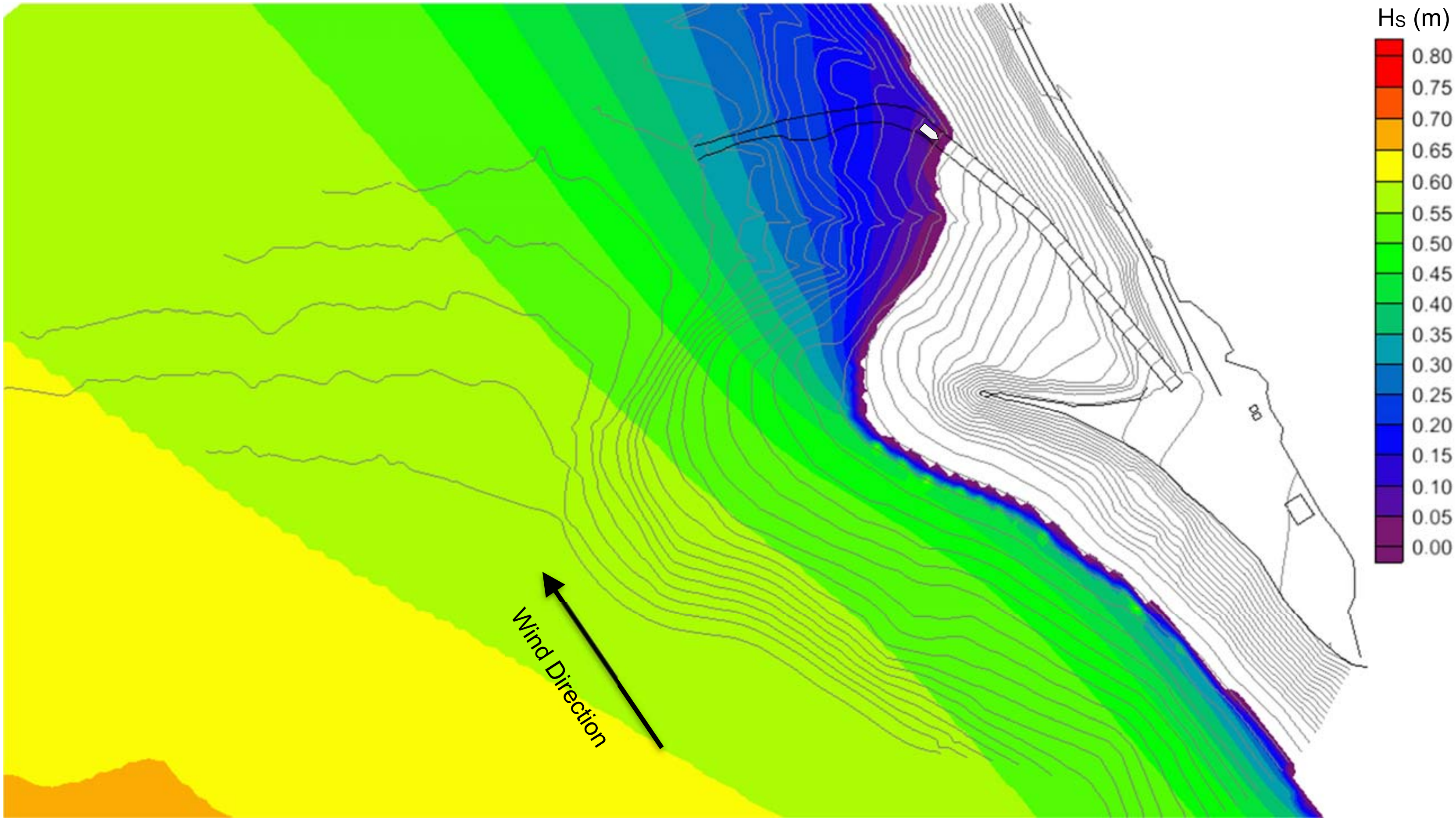
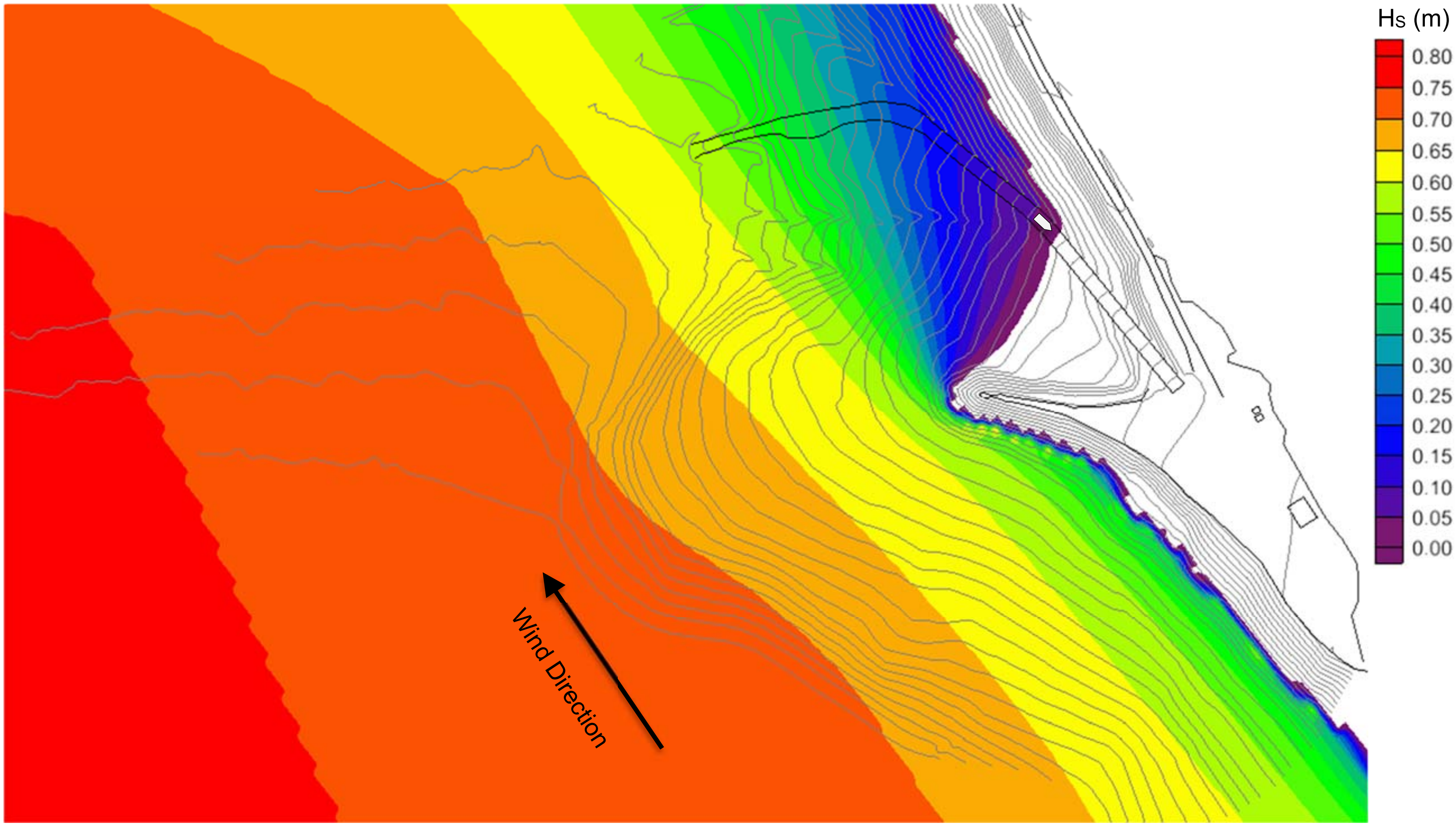
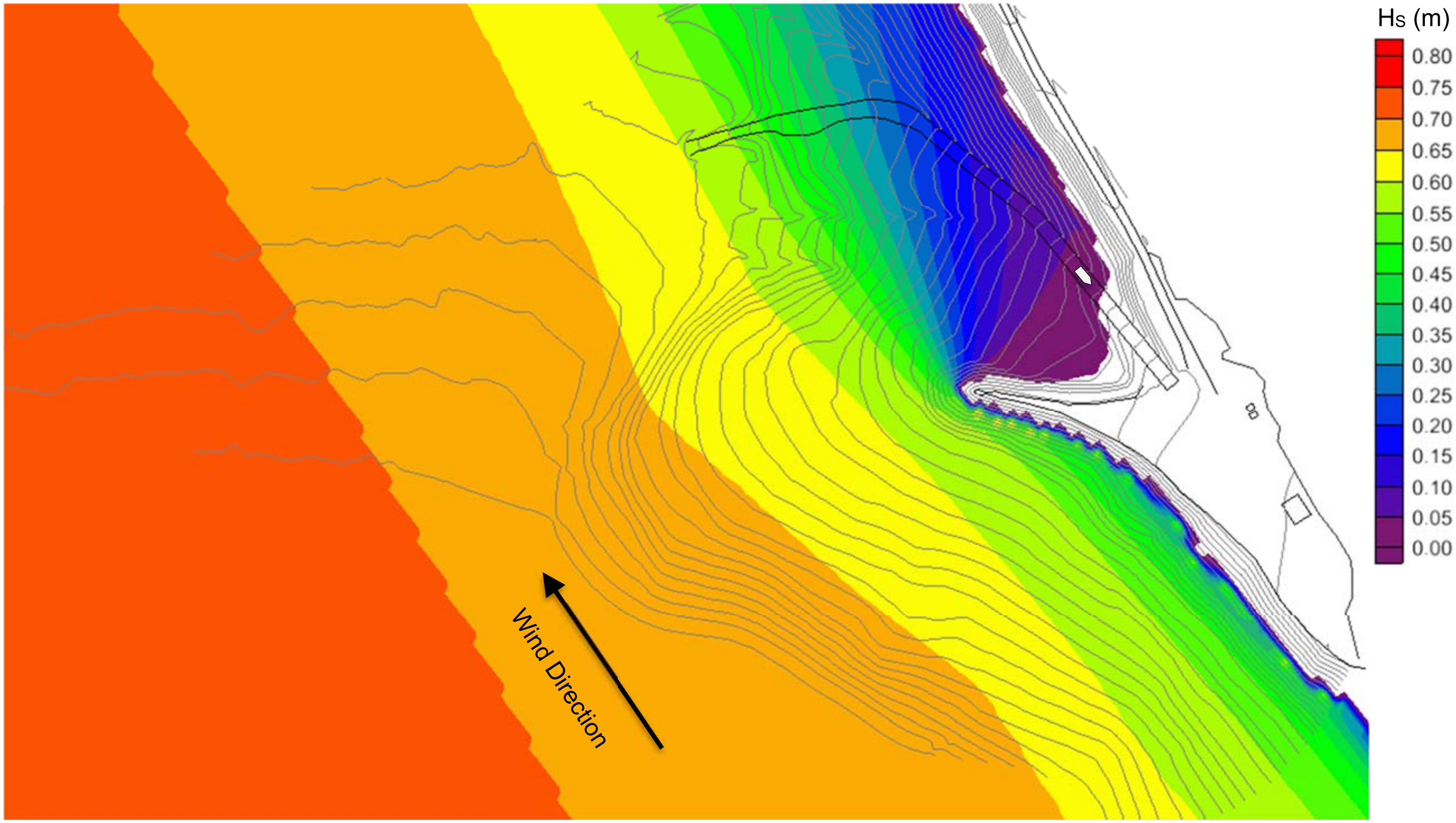


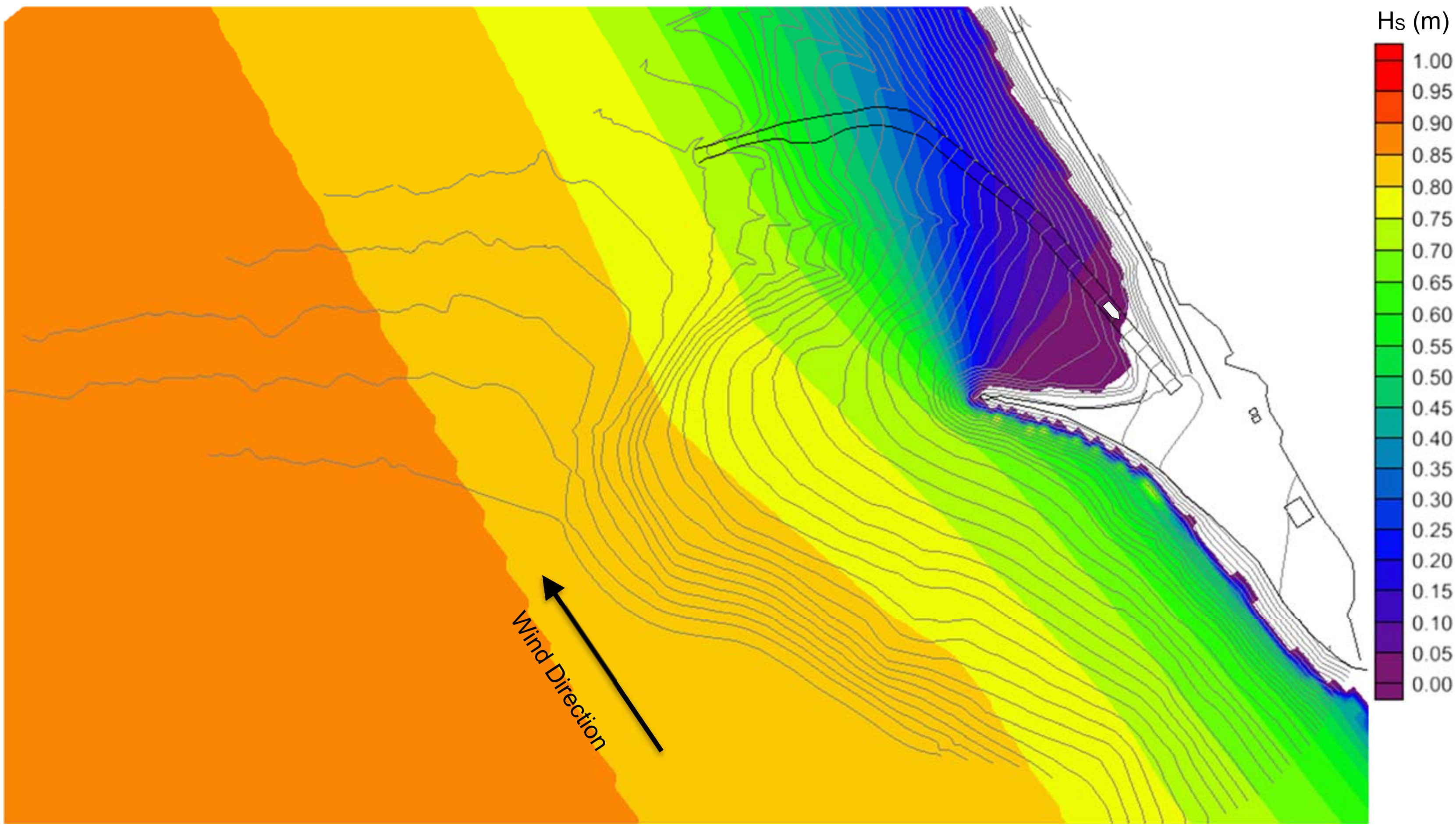
SIGNIFICANT WAVE HEIGHT VARIATION AT LAKE LEVEL 739.7 METERS, MAIN BOATING SEASON (LATE JUNE).



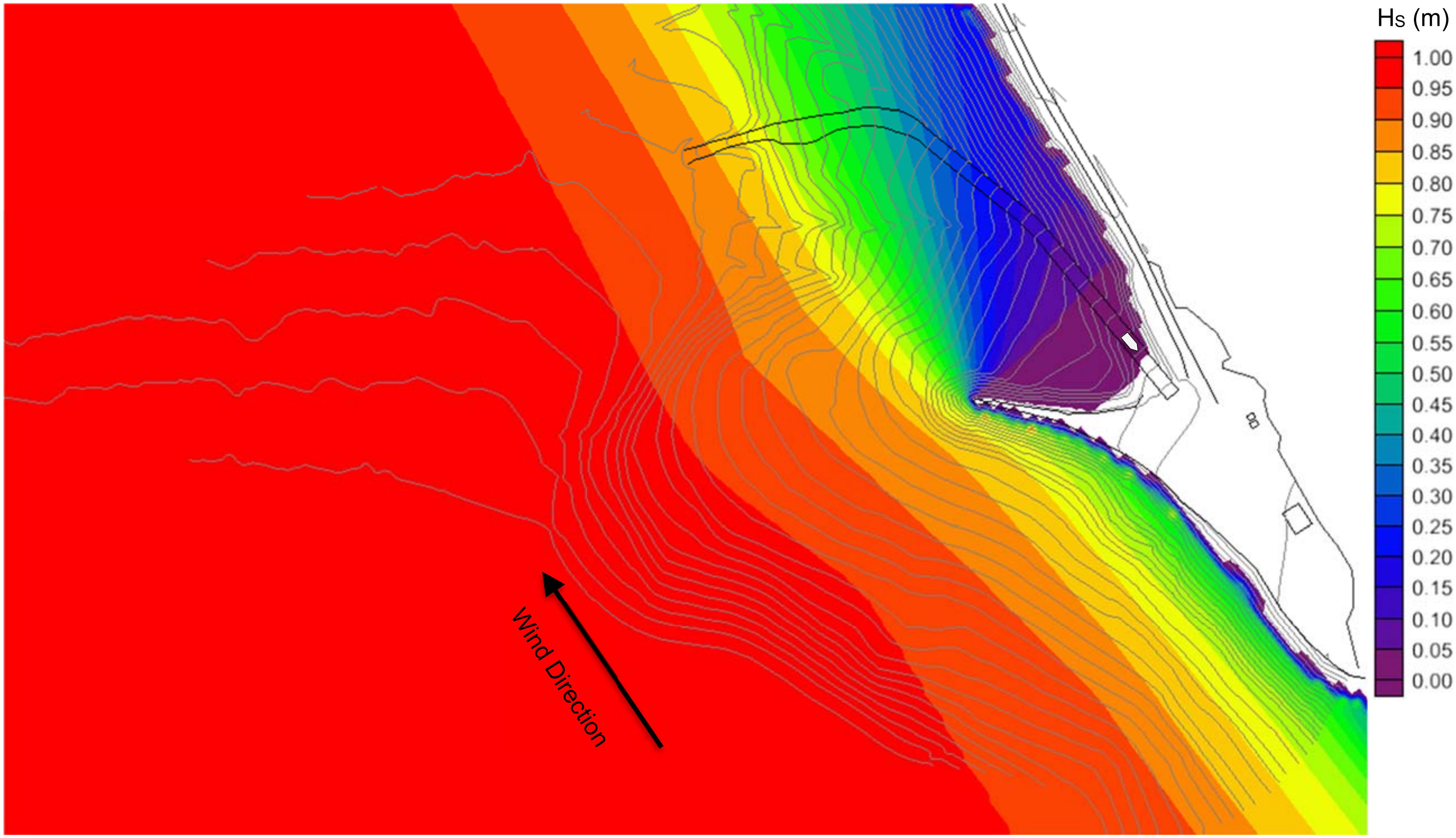
SIGNIFICANT WAVE HEIGHT VARIATION AT LAKE LEVEL 746.8 METERS, MAIN BOATING SEASON (JULY).



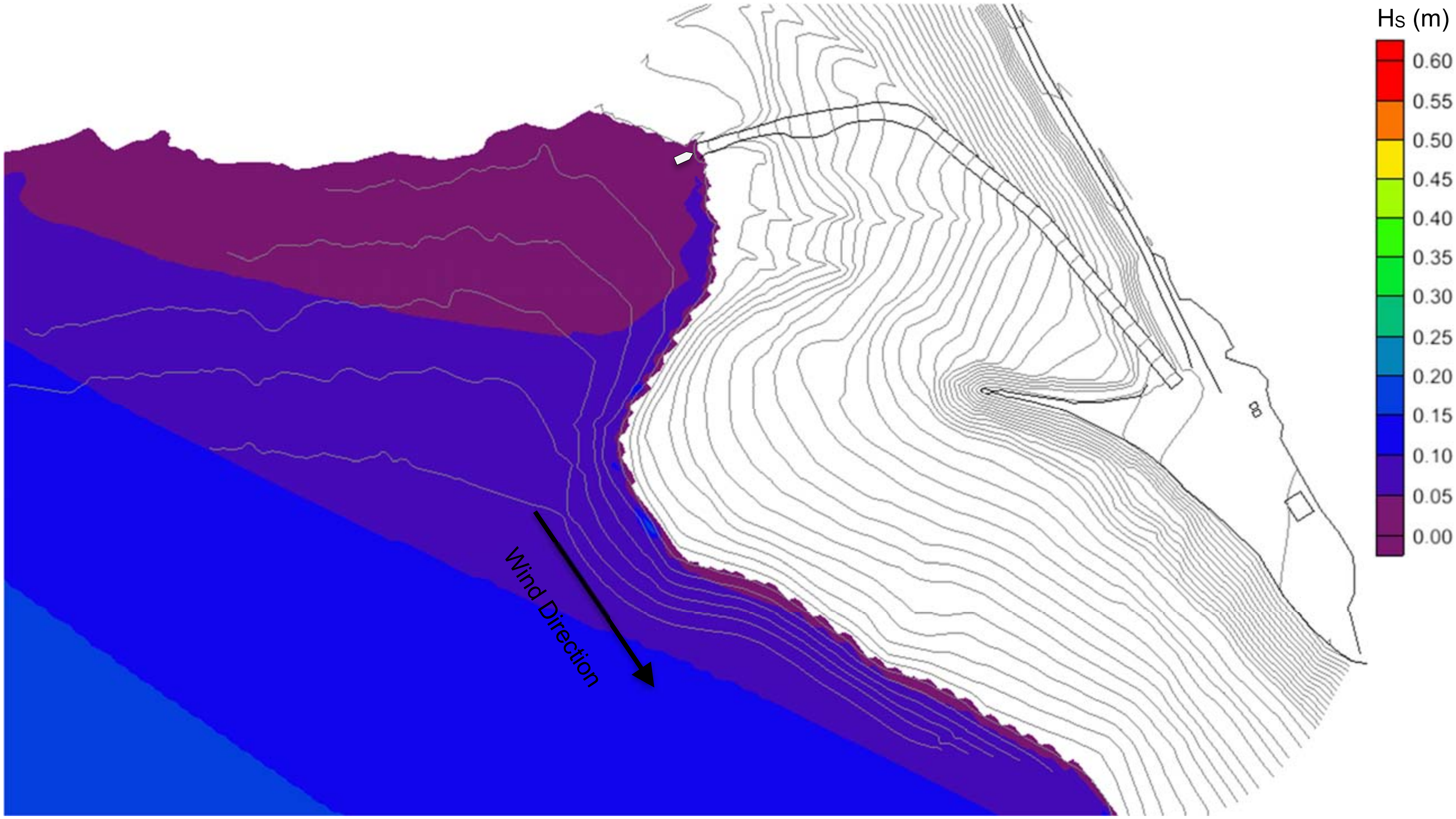
SIGNIFICANT WAVE HEIGHT VARIATION AT LAKE LEVEL 750.3 METERS, MAIN BOATING SEASON (AUGUST).



SIGNIFICANT WAVE HEIGHT VARIATION AT LAKE LEVEL 751.5 METERS, MAIN BOATING SEASON (EARLY SEPTEMBER).



SIGNIFICANT WAVE HEIGHT VARIATION AT LAKE LEVEL 753.5 METERS, SHOULDER SEASON (LATE SEPTEMBER).



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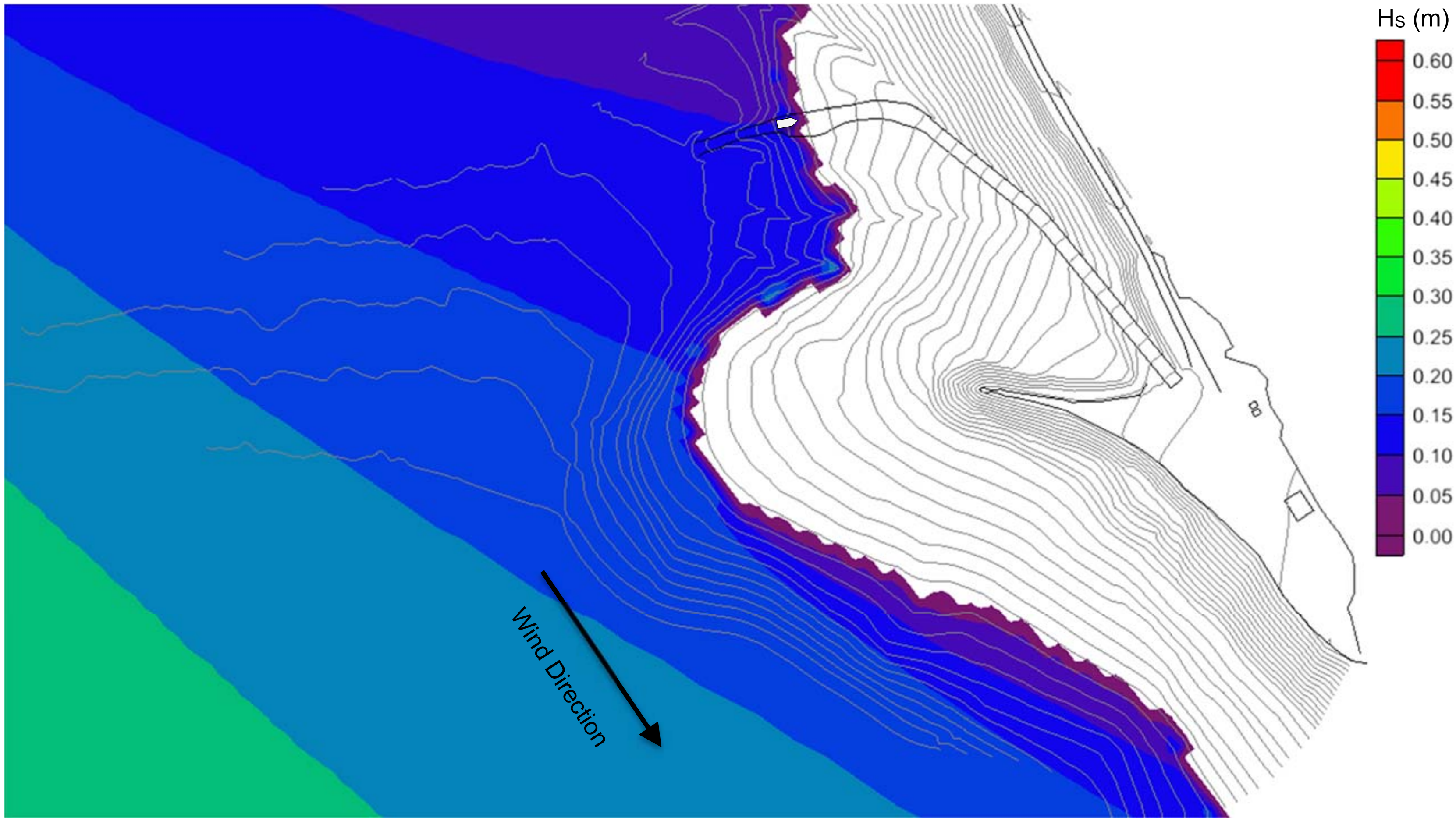

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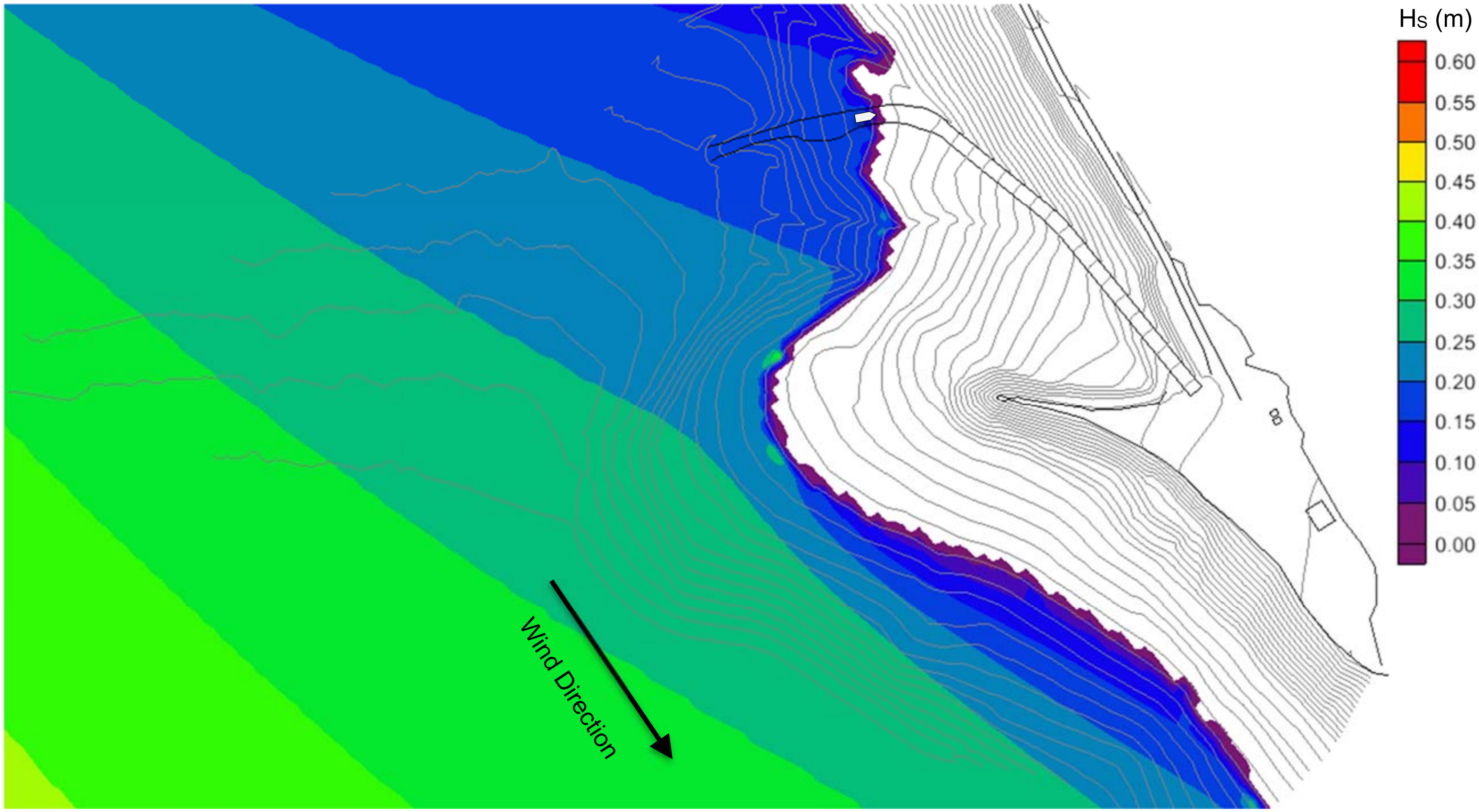

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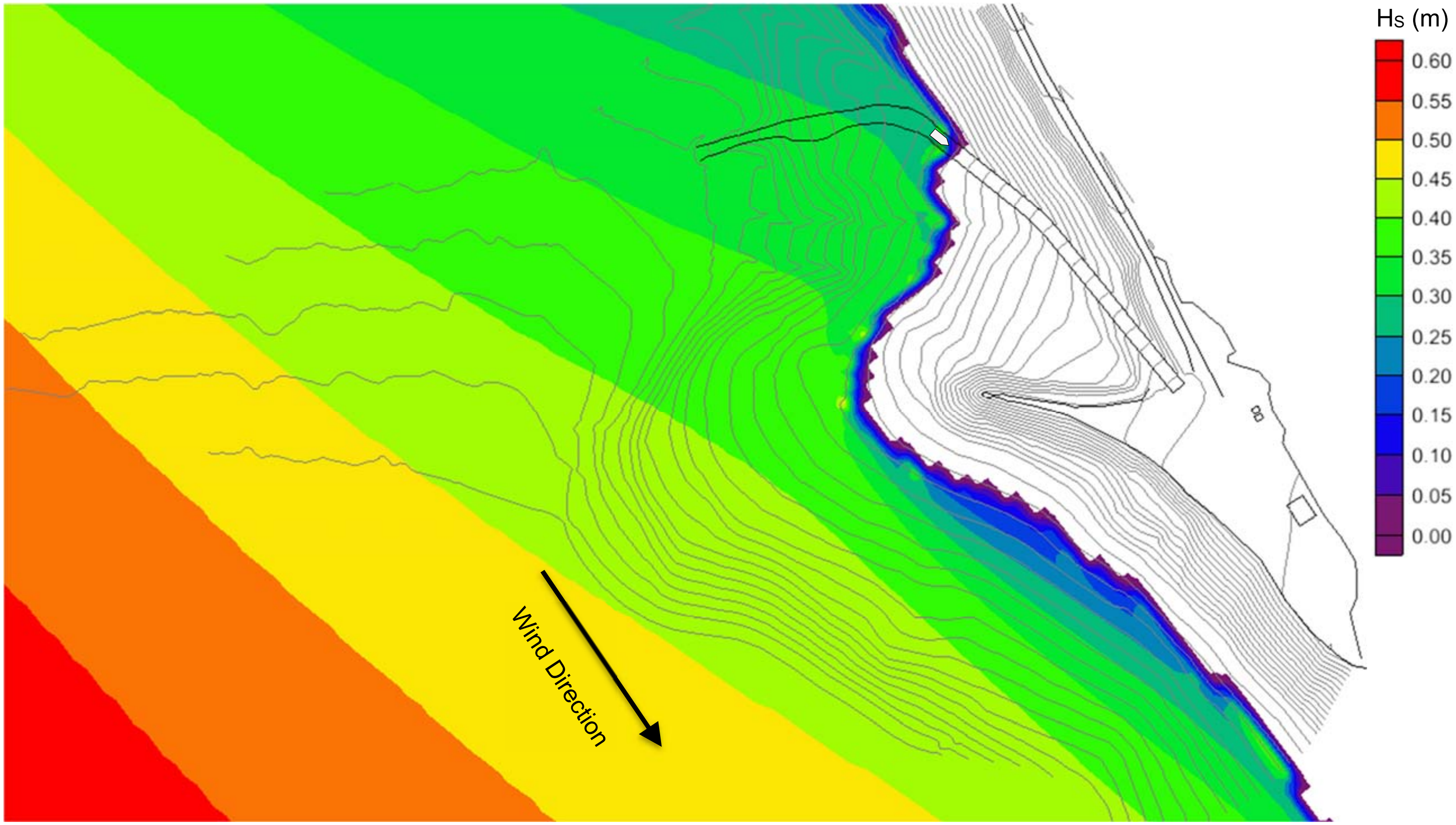

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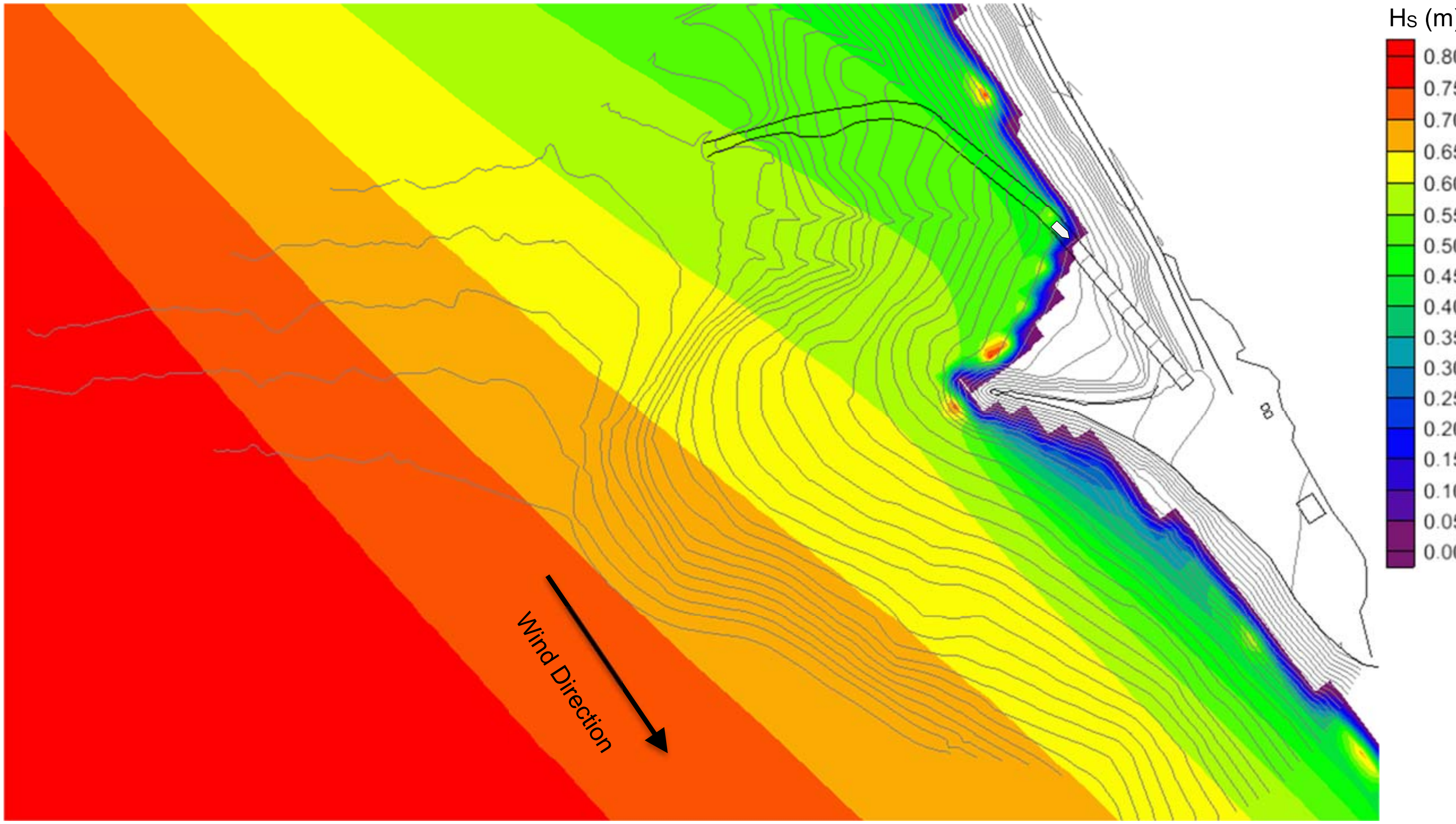

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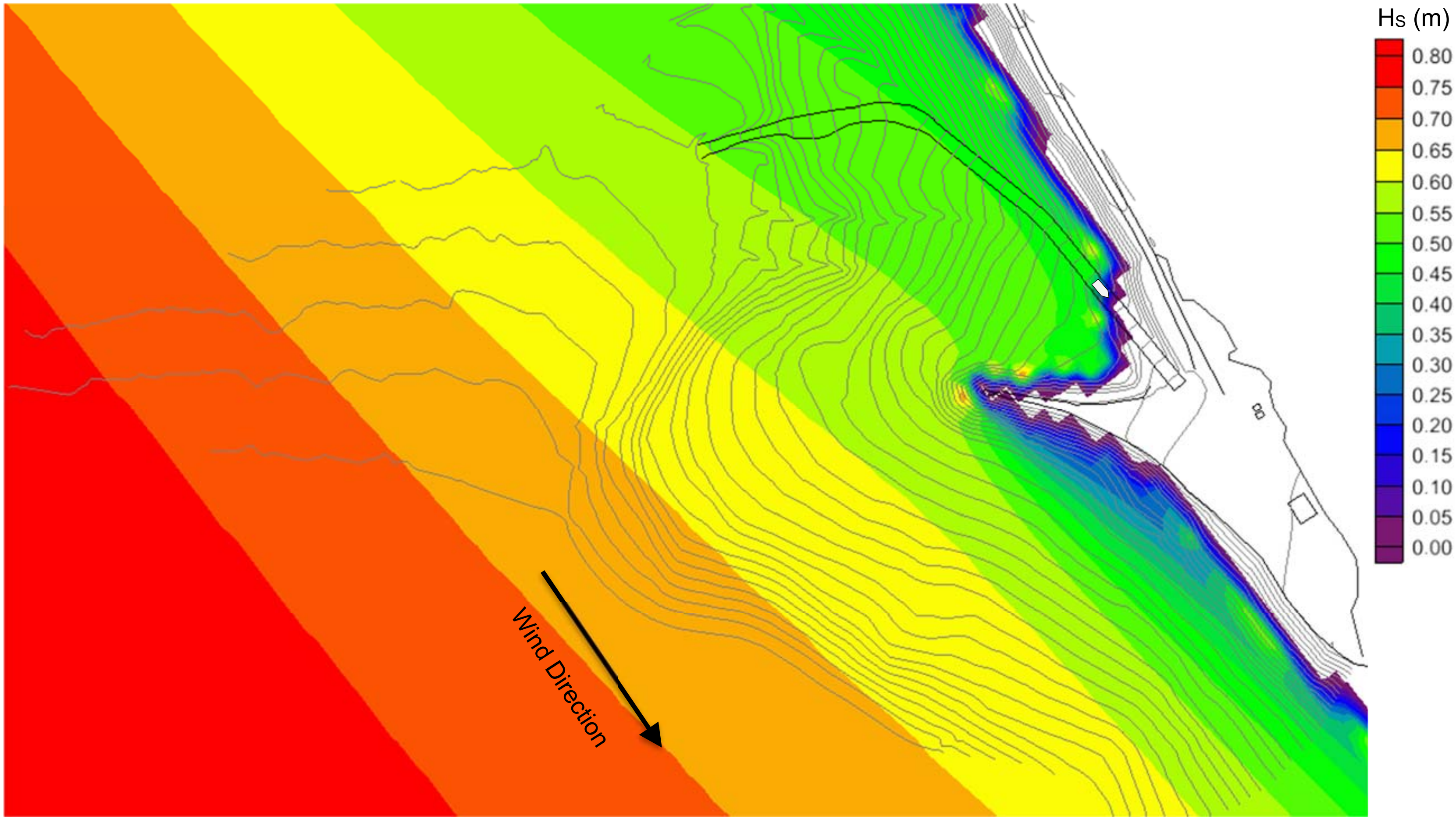
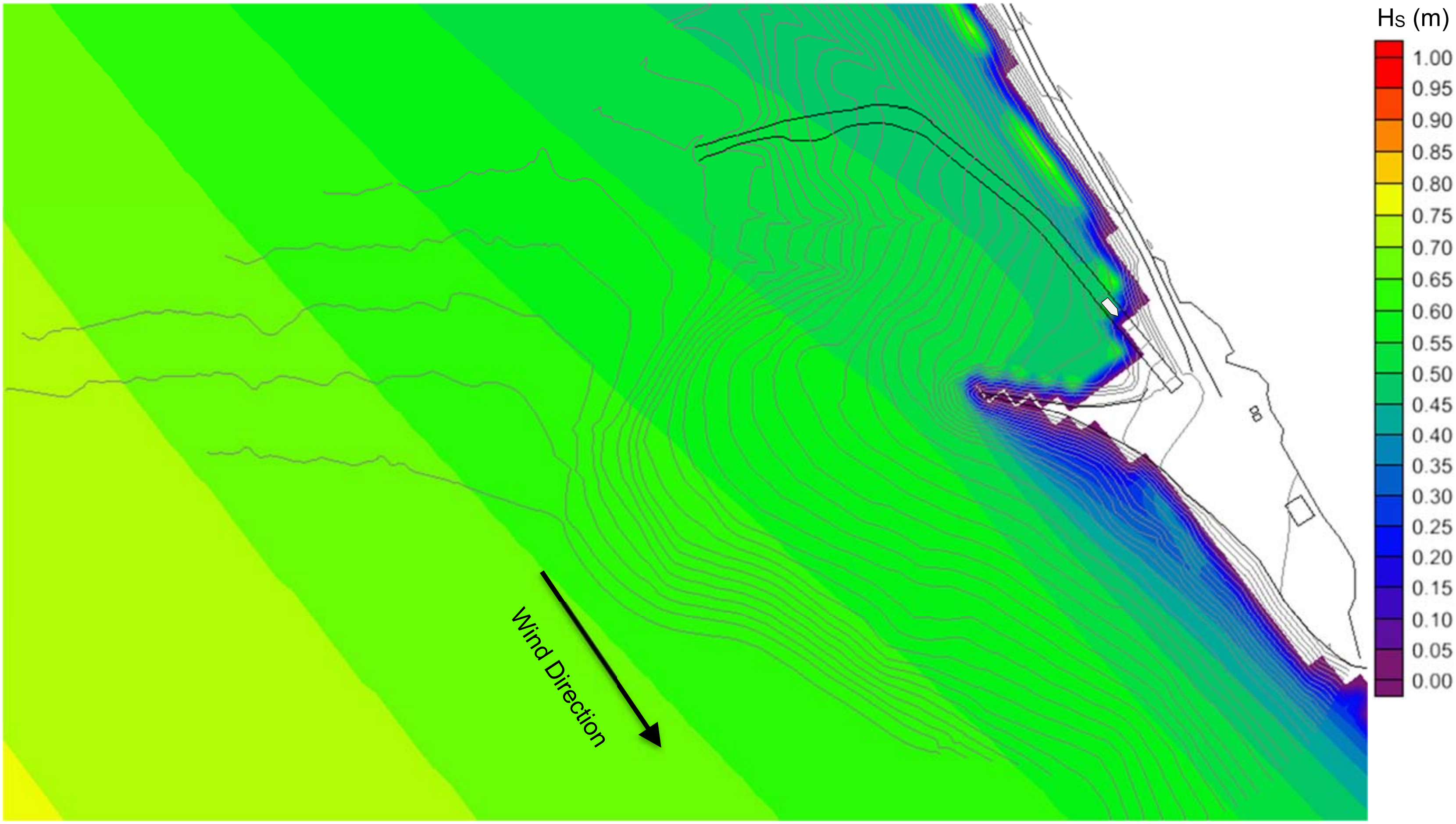
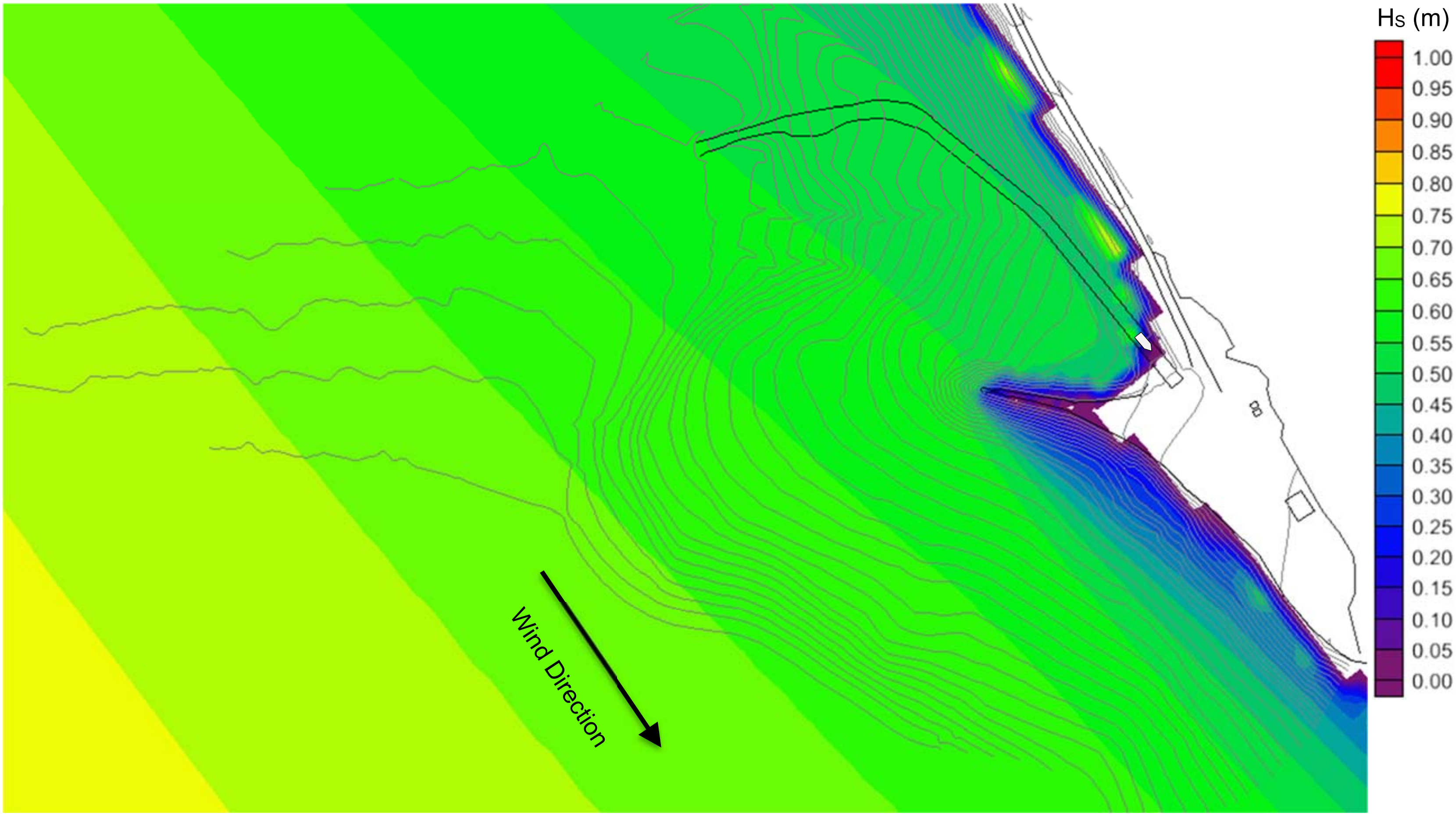


SIGNIFICANT WAVE HEIGHT VARIATION AT LAKE LEVEL 750.3 METERS, MAIN BOATING SEASON (AUGUST).



SIGNIFICANT WAVE HEIGHT VARIATION AT LAKE LEVEL 751.5 METERS, MAIN BOATING SEASON (EARLY SEPTEMBER).



SIGNIFICANT WAVE HEIGHT VARIATION AT LAKE LEVEL 753.5 METERS, SHOULDER SEASON (LATE SEPTEMBER).