

MEMORANDUM

To: Andy Bennett, P.E. (KPFF) and Will Cyrier, P.E.

From: Eduardo Sierra and Kathy Ketteridge, P.E., PhD

Date: January 9, 2022

Re: Luther Burnbank Marina Design: Wave and Wake Modeling

This technical memorandum summarizes the coastal engineering analysis completed by Blue Coast Engineering, LLC (Blue Coast) in support of the Luther Burnbank Marina design project. This evaluation developed empirical estimates of wind waves and wakes offshore of the Luther Burbank Marina and model predictions of wave/wake characteristics inside the marina based on proposed float layouts provided to Blue Coast by KPFF.

1. Extreme Winds

Wind data at Lake Washington were obtained from two sources: WDOT 520 Bridge (Latitude: 47.64 N, - Longitude: 122.26 W), and Renton Municipal Airport (Latitude: 47.49 N, Longitude: -122.21 W). Figure 1 shows a vicinity map as well as the wind station locations considered in this study. The data from these two sources were reviewed, statistically processed, and analyzed to develop an extremal analysis following the method of Goda (1984). Wind roses generated from the results of this analysis for both wind stations considered are also shown in Figure 1.

The shoreline in this area runs north to south along the northeastern corner of Mercer Island. The site is exposed to wind waves from the north-northeast (northerly) or south-southeast (southerly). Waves from the west and southwest are not expected to be significant at the site due to the small fetch distance across Lake Washington at the site from those directions. Due to the topography and project location with respect to the two wind stations, WDOT 520 Bridge station analysis was used for modeling wind waves from the northerly direction and wind from Renton Airport was considered for modeling wind waves approaching from the southerly direction. The 100-year (yr) wind speeds for these directions are provided in Table 1.

Table 1: 100-year Wind Speeds and Directions

Return Period Wind Year	Southerly – Renton Airport meters per second (mph)	Northerly – 520 Bridge meters per second (mph)
100-yr	24 (54)	18 (40)

2. Bathymetry Information

The coastal engineering evaluation conducted by Blue Coast utilized coastal bathymetry available to from a Lake Washington digital elevation model (DEM) NOS-NOAA bathymetry dataset. Additionally, site specific bathymetry, shown in Figure 2, was provided to Blue Coast by KPFF and was used to refine the bathymetry data set within the marina site.

3. Floating Breakwater Wave Transmission

The transmission of wave energy through the proposed floating wave attenuator dock units were estimated empirically outside the model using standard methods available in literature. This calculated transmission coefficient (ratio of transmitted wave over incoming wave height) was used as input to the wave model.

The method used to calculate the transmission coefficient was the relation proposed by Macagno referenced in Ruol et al (2013), shown in Equation 1. Different floating attenuator geometry combinations were used as input to Equation 1: widths of 8 feet (ft) and 10 ft and a drafts of 2 ft and 4 ft. Table 2 shows the calculated wave transmission coefficients for the different wave attenuator geometries evaluated.

$$k_{tM} = \frac{1}{\sqrt{1 + \left[kw \frac{\sinh kh}{2 \cosh (kh - kd)} \right]^2}} \quad \text{Equation 1}$$

where, k is the wave number, w is the width, h is the depth and d is the draft.

Table 2: Calculated Transmission Coefficients for Different Wave Attenuator Geometries

Attenuator Draft (ft)	Attenuator Width (ft)	Calculated Wave Transmission (% k_{tM})	Dock Configuration (See Figures 3-5)
2	8 ft	35 %	Option 6
4	8 ft	28 %	Option 3
2	10 ft	28 %	Option 5
4	10 ft	23 %	Option 1 / Option 2 / Option 4

4. Proposed Alternatives: Marina Dock Configurations

KPFF provided Blue Coast with six different dock configurations (listed below) that were evaluated as part of this analysis. These dock configurations are shown in the Figures 3-5.

Description of Marina Configurations:

- Option 1: Current design: 193' x 10' x 4' draft main float
- Option 2: Current design extended (no dog leg): 210.5' x 10' x 4' draft main float
- Option 3: Narrower: 193' x 8' x 4' draft main float
- Option 4: Shorter: 173' x 10' x 4' draft main float (inner float +25')
- Option 5: Lighter: 193' x 10' x 2' draft main float
- Option 6: Minimum: 173' x 8' x 2' draft main float (inner float +25')

5. Wind Wave Modeling

Wave numerical modeling using northerly and southerly 100-year wind speeds provided in Table 1 to develop predictions of wave characteristics within the Luther Burbank Marina site for proposed dock configurations shown in Figures 3 through 5. The model SWAN (Simulating WAVes Nearshore), a third-generation spectral finite difference wave model, was utilized to for this work (Holthuijsen et al., 2006). SWAN utilizes lake bathymetry, incident wave spectra, and local wind conditions to generate and transform waves into the nearshore environment.

The model grid utilized bathymetry data described in Section 2 of this Memorandum. The entire modeling domain is shown in Figure 2. A higher resolved nested grid was used during the modeling in order to accurately transform the waves within the marina vicinity. The largest grid has a grid cell size of 50 ft, and the grid at the project site has a grid cell spacing of 3 ft.

Due to the lack of local wave data no SWAN model calibration for the Luther Burbank project conditions was conducted. Therefore, appropriate factors of safety should be applied to structural calculations conducted using results of the wave modeling provided in this memorandum.

Results for these 100-year wind-wave model simulations for the larger model domain are provided in Figure 6. Results in the vicinity of the Project Site, where the modeling grid had greater resolution with the different dock configurations described in Section 4 are shown in Figures 7-12. Higher waves are represented in red color, and blue color represents smaller or no waves.

Table 3 shows predicted waves at three extraction points inside the marina and one point outside the marine (see Figure 19) for the 6 marina options proposed by KPFF.

Table 3: Predicted Wind-Wave Heights at Specific Points Inside and Outside the Marina

	Scenario	Sig Wave Height (Hs, ft)			
		P1	P2	P3	P4
Option 1	100-yr Northerly Wind Waves	1.1	1.3	0.5	1.7
	100-yr Southerly Wind Waves	1.5	1.3	1.1	2.1
Option 2	100-yr Northerly Wind Waves	1.1	1.3	0.5	1.7
	100-yr Southerly Wind Waves	1.6	1.3	1.4	2.1
Option 3	100-yr Northerly Wind Waves	1.1	1.3	0.6	1.7
	100-yr Southerly Wind Waves	1.5	1.3	1.1	2.1
Option 4	100-yr Northerly Wind Waves	1.1	1.3	0.5	1.7
	100-yr Southerly Wind Waves	1.5	1.3	1.2	2.1
Option 5	100-yr Northerly Wind Waves	1.1	1.3	0.6	1.7
	100-yr Southerly Wind Waves	1.5	1.3	1.1	2.1
Option 6	100-yr Northerly Wind Waves	1.1	1.3	0.7	1.7
	100-yr Southerly Wind Waves	1.5	1.4	1.3	2.1

Wave modeling results show that 100-yr southerly winds produced higher wave heights than northerly winds outside and inside the marina. The open entrance at the south side of the marina allows intrusion of southerly waves. Wave extraction in the vicinity of Point 1 presented higher waves indicating that this area is less sheltered from southerly wind-waves. The north side of the marina also allows some wave energy penetration, (near extraction Point 2) however wave energy from northerly winds is less severe than from southerly wind directions. Dock Options 1 and 4 showed the lowest wave height values inside the marina whereas the highest wave height values were observed for Option 6.

The dog leg shown in Option 1 at the south end of the wave attenuator provides additional protection to the finger piers located at the southern end of the wave attenuator dock compared to the extended (no dog leg) Option 2. Wave heights at those finger piers is reduced by 30% for the dog leg Option 1 (see Figure 7) compared to only 10% reduction for the extended (no dog leg) Option 2 (see Figure 8).

6. Boat Wake Modeling

In addition to wind-waves, the project site is also impacted by boat wakes due to vessels traversing past the site, sometimes at high rates of speed. Therefore, additional wave modeling was conducted to evaluate boat wake heights inside the marina for the same 6 Dock Options evaluated for wind-waves (Section 5).

A specific vessel survey identifying types and frequencies of vessels passing the project site was not available for use in this evaluation. Therefore, typical vessels and operational criteria for these vessels were used to inform this evaluation.

Typical wakeboard and waterski boats vary in length from 16 to 24 ft. Based on observed boats on the lake and research conducted by Glamore (2009) on waves generated by waterski and wakeboard boats, a vessel length of 20 ft and an 8 ft beam will produce a wave height of approximately 3 ft and a wave period of 2 seconds. This wake height is expected to decrease exponentially from the sailing line to approximately 1.6 ft outside the marina (Rupretch, J. et al, 2015).

These wake parameters were input in the wave propagation model and tested for the two different traveling direction for the vessel (travelling south and travelling north) and six different alternatives shown in Figures 3 through 5. The wake model results for these alternatives are shown in Figures 13 through 18, where higher wakes are represented in red color, and blue color represents smaller or no wakes. Table 4 summarizes wave heights for these model simulations at the same four extraction points as the wind-wave modeling results (see Figure 19).

Review of the modeling completed for boat wakes show that boats traveling from the north to the south produce smaller wakes inside the marina than boat travelling from the south to the north for all dock options evaluated. Predicted wake heights inside the marina were similar for all dock options evaluated for the same direction of boat travel.

Similarly, there is little difference in predicted boat wake heights within the marina between the dog leg used in Option 1 compared to the extended (no dog leg) Option 2.

Table 4: Predicted Boat Wake Heights at Specific Points Inside and Outside the Marina

	Scenario	Wake Height (H, ft)			
		P1	P2	P3	P4
Option 1	N → S Boat Wake	0.6	0.8	0.3	1.5
	S → N Boat Wake	0.7	0.7	0.5	1.5
Option 2	N → S Boat Wake	0.6	0.8	0.4	1.5
	S → N Boat Wake	0.7	0.7	0.7	1.5
Option 3	N → S Boat Wake	0.6	0.8	0.4	1.5
	S → N Boat Wake	0.7	0.7	0.6	1.5
Option 4	N → S Boat Wake	0.6	0.8	0.3	1.5
	S → N Boat Wake	0.7	0.7	0.6	1.5
Option 5	N → S Boat Wake	0.6	0.8	0.4	1.5
	S → N Boat Wake	0.7	0.7	0.6	1.5
Option 6	N → S Boat Wake	0.7	0.9	0.5	1.5
	S → N Boat Wake	0.8	0.7	0.7	1.5

7. Summary

A coastal engineering analysis was completed to develop winds and wave parameters sufficient for the design and for developing design criteria. Winds applicable to the project area are predominantly from the north-northwest (northerly) and south-southeast (southerly).

100-year southerly winds produced higher waves outside and inside the marina than northerly winds. Southerly wind-waves enter from the south end to the marina producing the higher wave energy inside the marina.

Wind-wave model using Options 1 and 4 predicted the lowest wave height values inside the marina. Option 6 presented the highest waves observed inside the marina due to the lowest draft and shortest width considered.

The dog leg located at the south end of the wave attenuator for Option 1 provides additional protection to the marina compared to the extended (no dog leg) Option 2 by reducing the wind wave heights from 10% to 30% at the finger floats located on the lee side of the wave attenuator dock. This benefit is not seen in the boat wake modeling results.

The highest boat-wake height values were observed when evaluating Option 6 due to the lowest draft (2 ft) and shortest width (8 ft) considered for this alternative. However, the wake model predicted similar wake heights inside the marina for all marina dock configurations.

The 100-year wind-wave produce longer wave periods than boat wake periods and, therefore, higher wave transmission is expected during a large extreme wind event.

8. Closure

This document has been prepared by Blue Coast Engineering LLC. in accordance with generally accepted engineering practices and is intended for the exclusive use and benefit of KPFF and their authorized representatives for specific application to the Luther Burbank project in Lake Washington. The contents of this document are not to be relied upon or used, in whole or in part, by or for the benefit of others without specific written authorization from Blue Coast Engineering LLC. No other warranty, expressed or implied, is made. Blue Coast Engineering LLC and its officers, directors, employees, and agents assume no responsibility for the reliance upon this document or any of its contents by any parties other than KPFF.

9. References

Adapted from the theoretical predictor of J. Cox (1988) to account for angle of wave incidence and to reflect experimental results in 3-D wave fields using irregular waves.

Glamore, W.C. 2009. "A Decision Support Tool for Assessing the Impact of Boat Wake Waves on Inland Waterways." http://www.pianc.org/downloads/dwa/Wglamore_DPWApaper.pdf.

Holthuisen, L.H., Booij, N., Ris, R.C., Haagsma, J.G., Kieftenburg, A.T.M.M., and Kriezi, E.E. 2006. SWAN Cycle III version 40.51 User Manual. Delft University of Technology, Netherlands.

National Oceanographic and Atmospheric Administration. 2020. National Oceanographic and Atmospheric Administration Bathymetry & Digital Elevation Models, <http://maps.ngdc.noaa.gov/viewers/bathymetry/>.

NOAA bathymetry (2005) Combined bathymetry and topography of the Puget Lowlands, Washington State (tile: g1225480 and g1225475). Data originator; David Finlayson, School of Oceanography, University of Washington [accessed September 2, 2020 at <http://www.ocean.washington.edu/data/pugetsound/>]

Ruol, Piero & Martinelli, Luca & Pezzutto, Paolo. (2013). Formula to Predict Transmission for -Type Floating Breakwaters. Journal of waterway, port, coastal, and ocean engineering. 139. 1-8. 10.1061/(ASCE)ww.1943-5460.0000153.

Ruprecht, J. E., Glamore, W.X., Cogle, I.R., & Flocard, F. 2015. Wakesurfing. Some wakes are more equal than others. In Australasian Coasts & Ports Conference 2015: 22nd Australasian Coastal and Ocean Engineering Conference and the 15th Australasian Port and Harbour Conference (. 779). Engineers Australia and IPENZ.

FIGURES

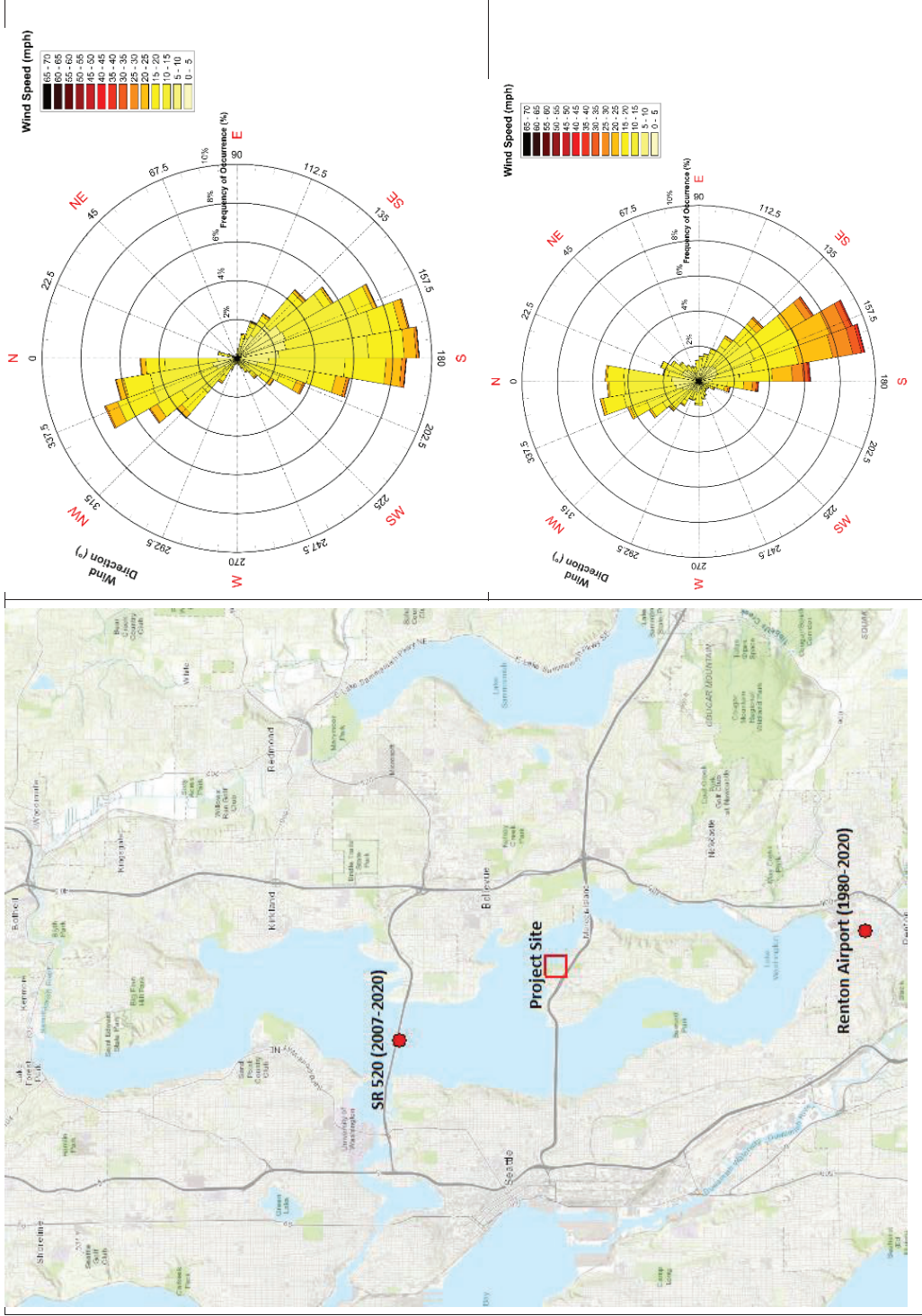


Figure 1. Left: Location of Project Site and Wind Stations used in the Evaluation. Upper Right: Wind Rose for 520 Bridge Station (2007-2020) and Bottom Right: Wind Rose for Renton Municipal Airport (1980-2020)

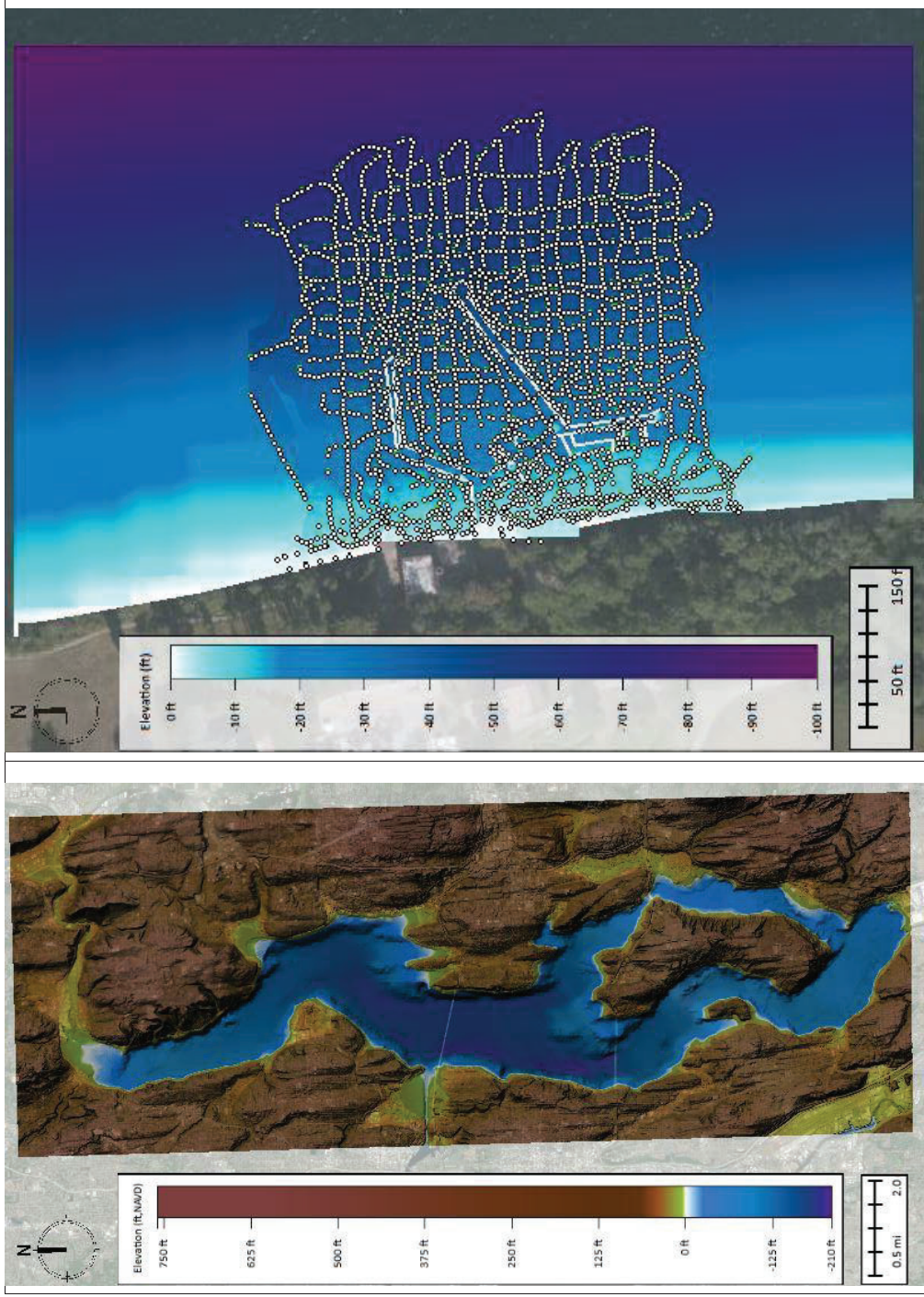
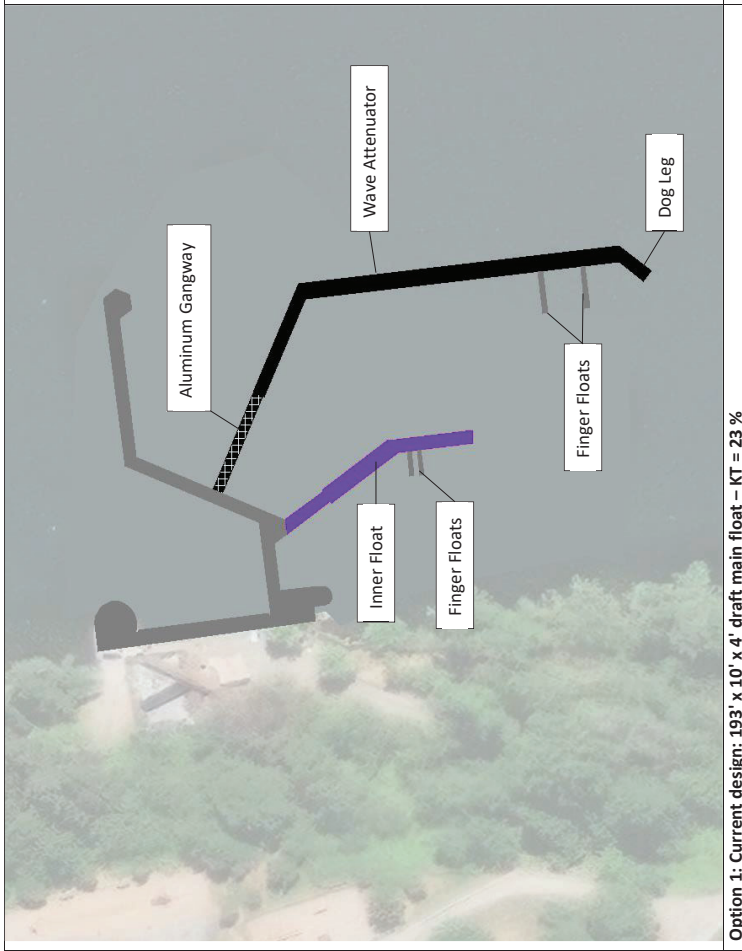
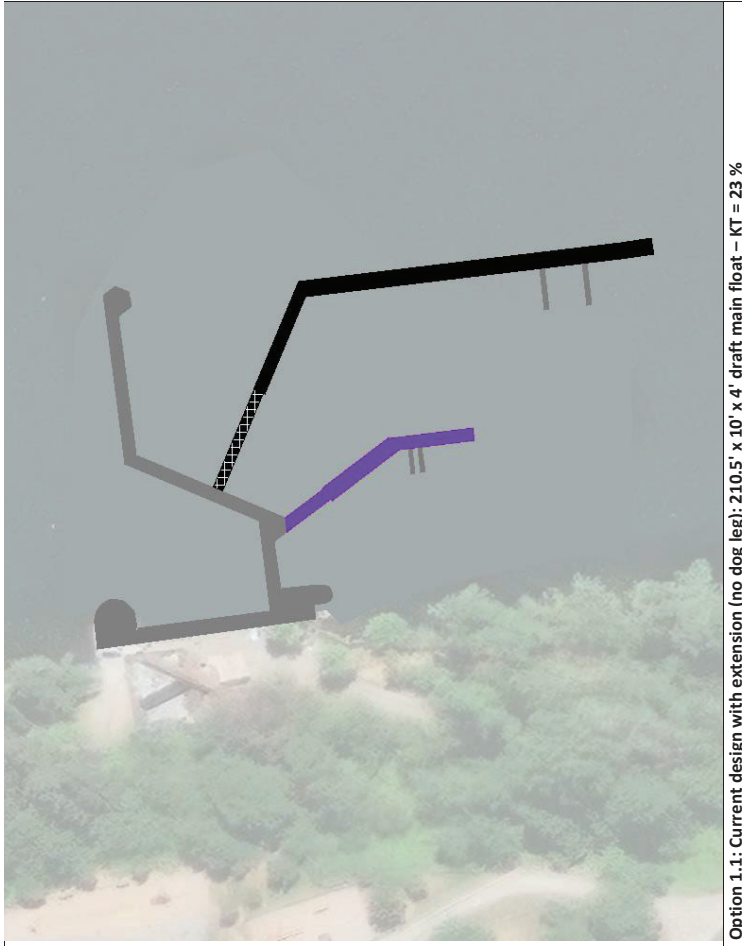


Figure 2. Left: Combined Bathymetry and Topography cropped to Lake Washington and NOAA NOS hydrographic data H11810 (2008) and H11376 (2005). Right: Bathymetric Survey (white dots) merged with NOAA NOS hydrographic data H11376 (2005) at the project site.

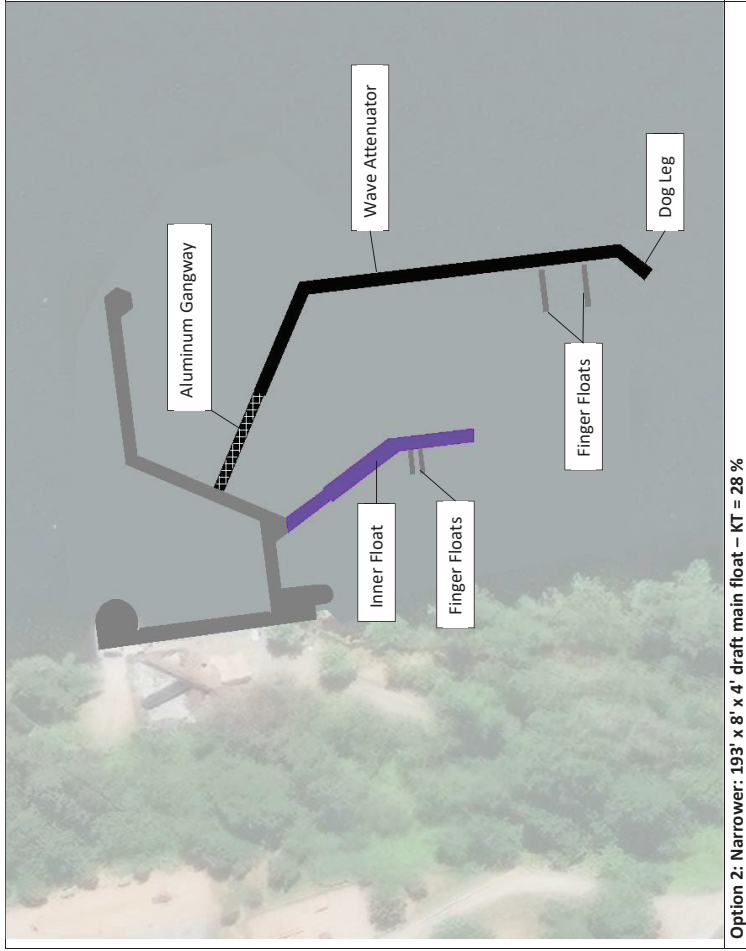


Option 1: Current design: 193' x 10' x 4' draft main float – KT = 23 %

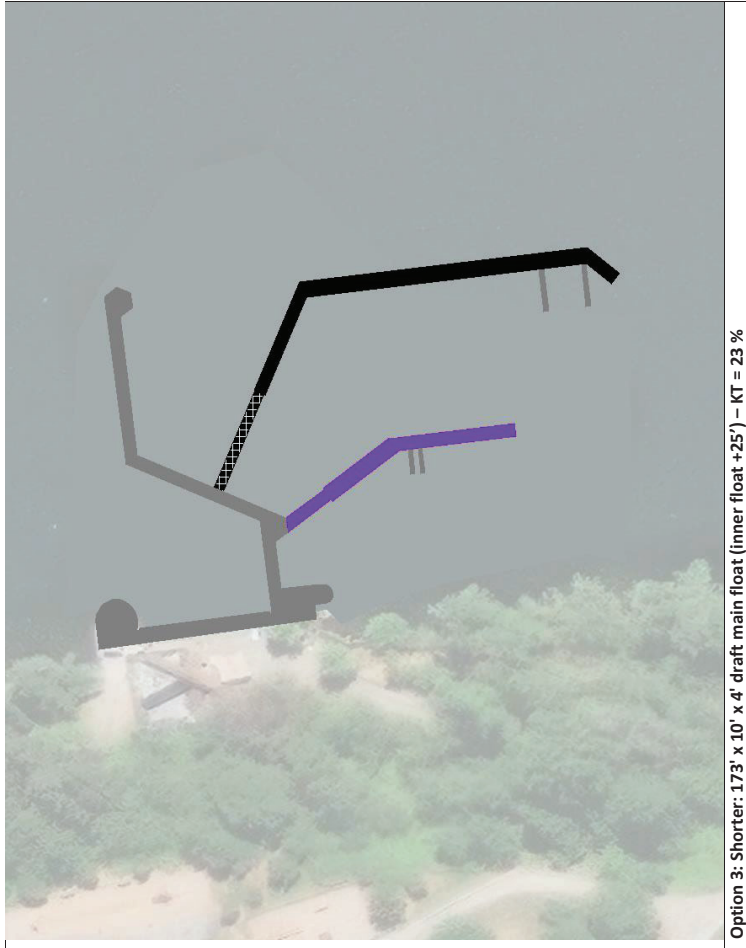


Option 1.1: Current design with extension (no dog leg): 210.5' x 10' x 4' draft main float – KT = 23 %

Figure 3: Dock Configurations used in the Wave and Boat Wake Numerical Modeling Evaluation.

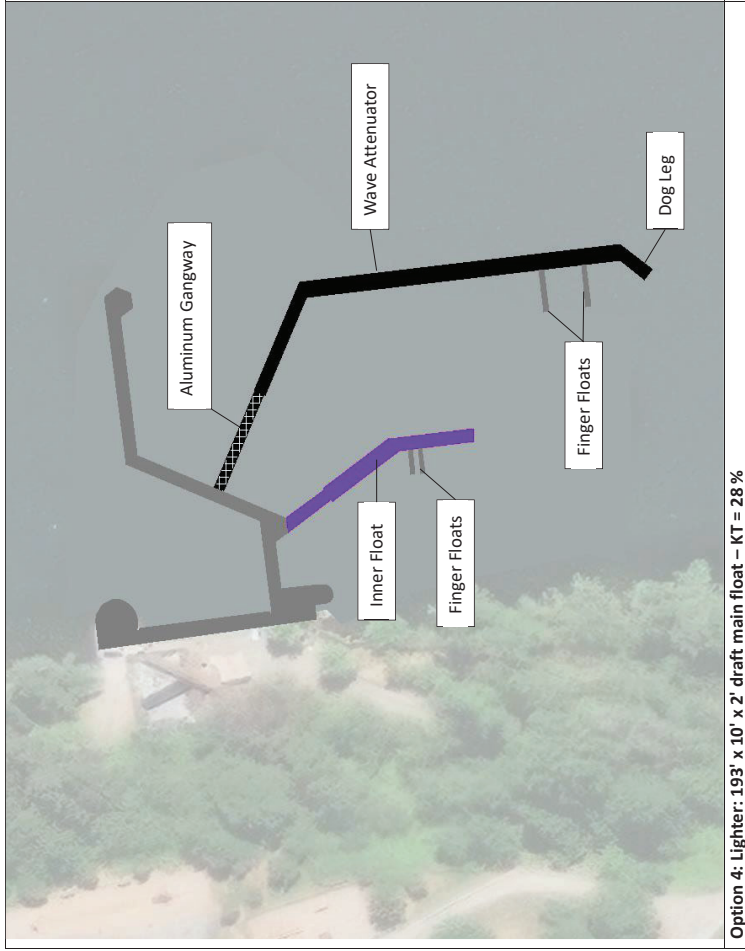


Option 2: Narrower: 193' x 8' x 4' draft main float - KT = 28 %

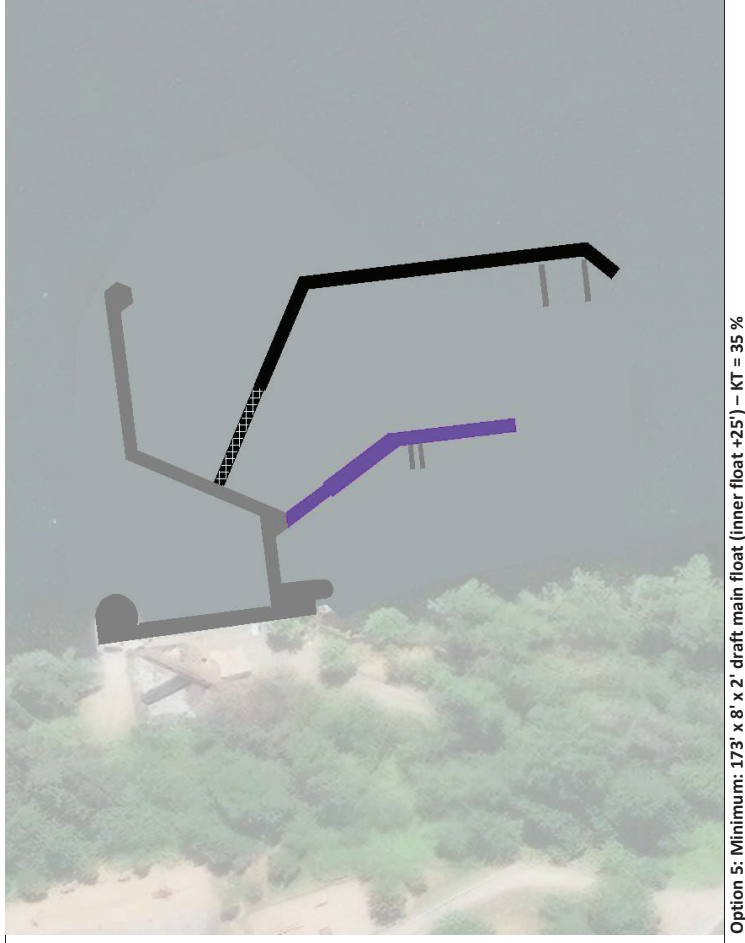


Option 3: Shorter: 173' x 10' x 4' draft main float (inner float +25') - KT = 23 %

Figure 4: Dock Configurations used in the Wave and Boat Wake Numerical Modeling Evaluation.



Option 4: Lighter: 193' x 10' x 2' draft main float - KT = 28%



Option 5: Minimum: 173' x 8' x 2' draft main float (inner float +25') - KT = 35%

Figure 5: Dock Configurations used in the Wave and Boat Wake Numerical Modeling Evaluation.

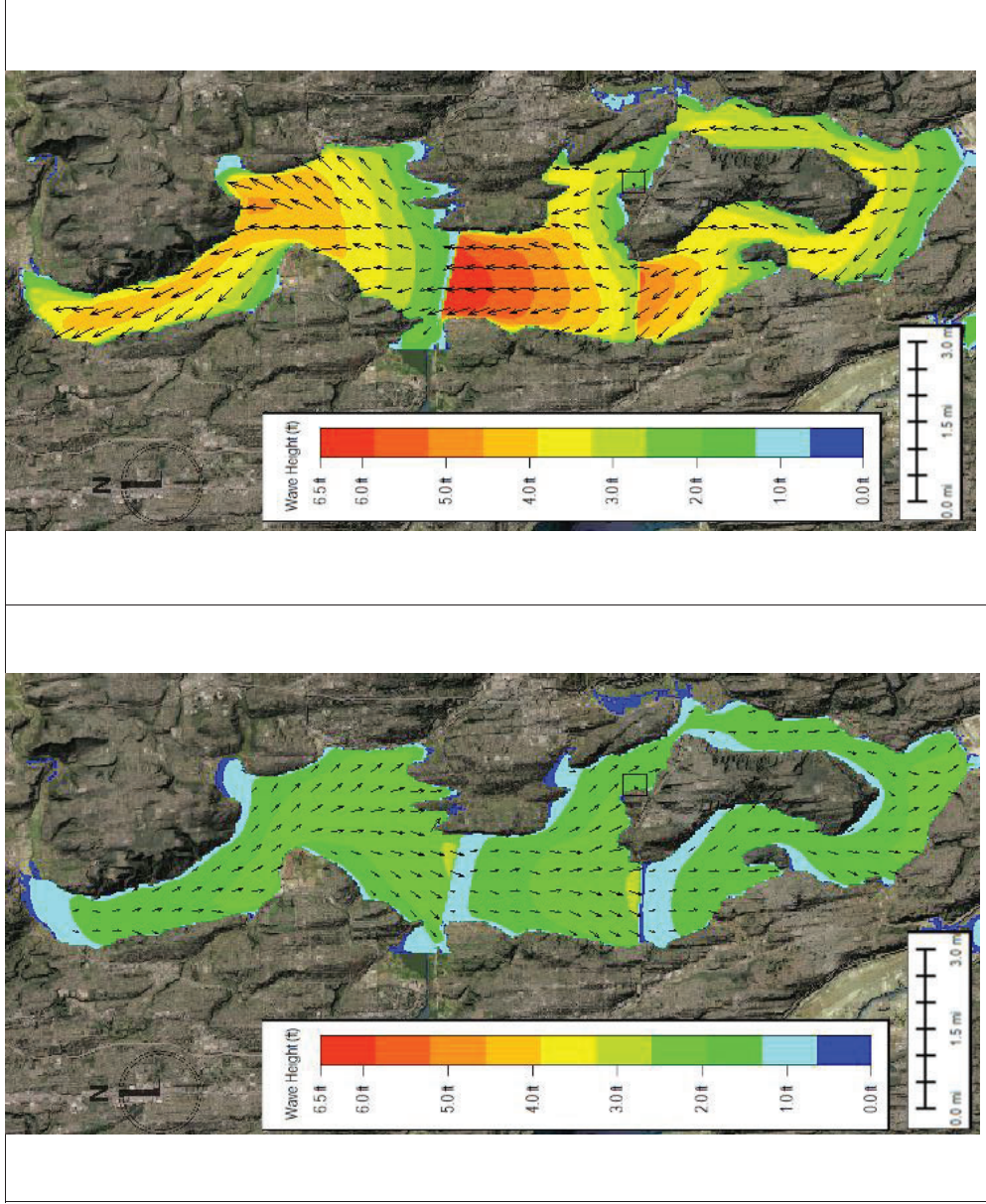


Figure 6. Simulated results for Lake Washington Northernly 100-yr return period wind (left) and 100-yr return period southerly wind (right).

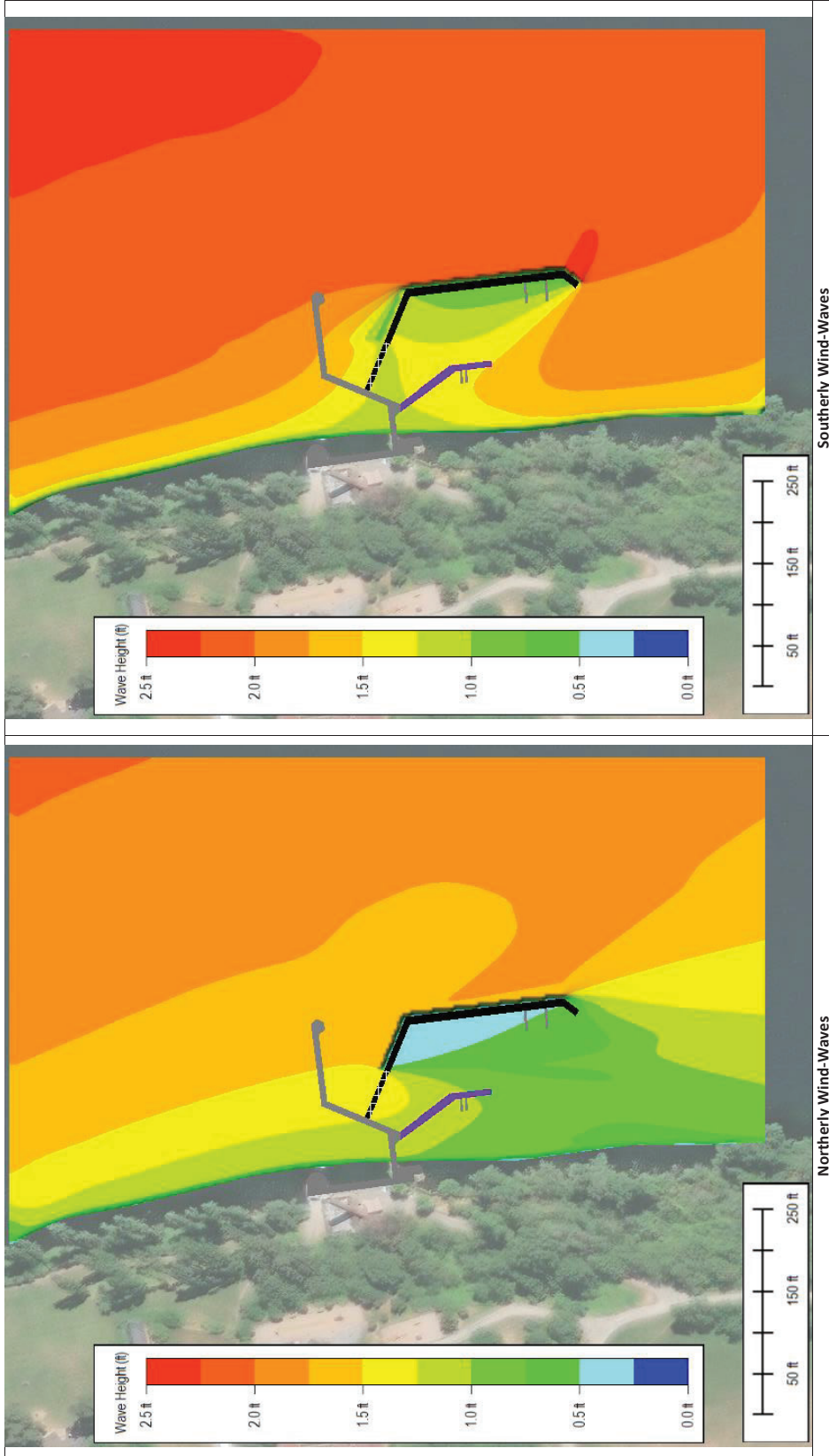


Figure 7: Plan View of Resulting 100-year Significant Wind-Wave Heights for Option 1: Current design: 193' x 10' x 4' draft main float – KT = 23 %

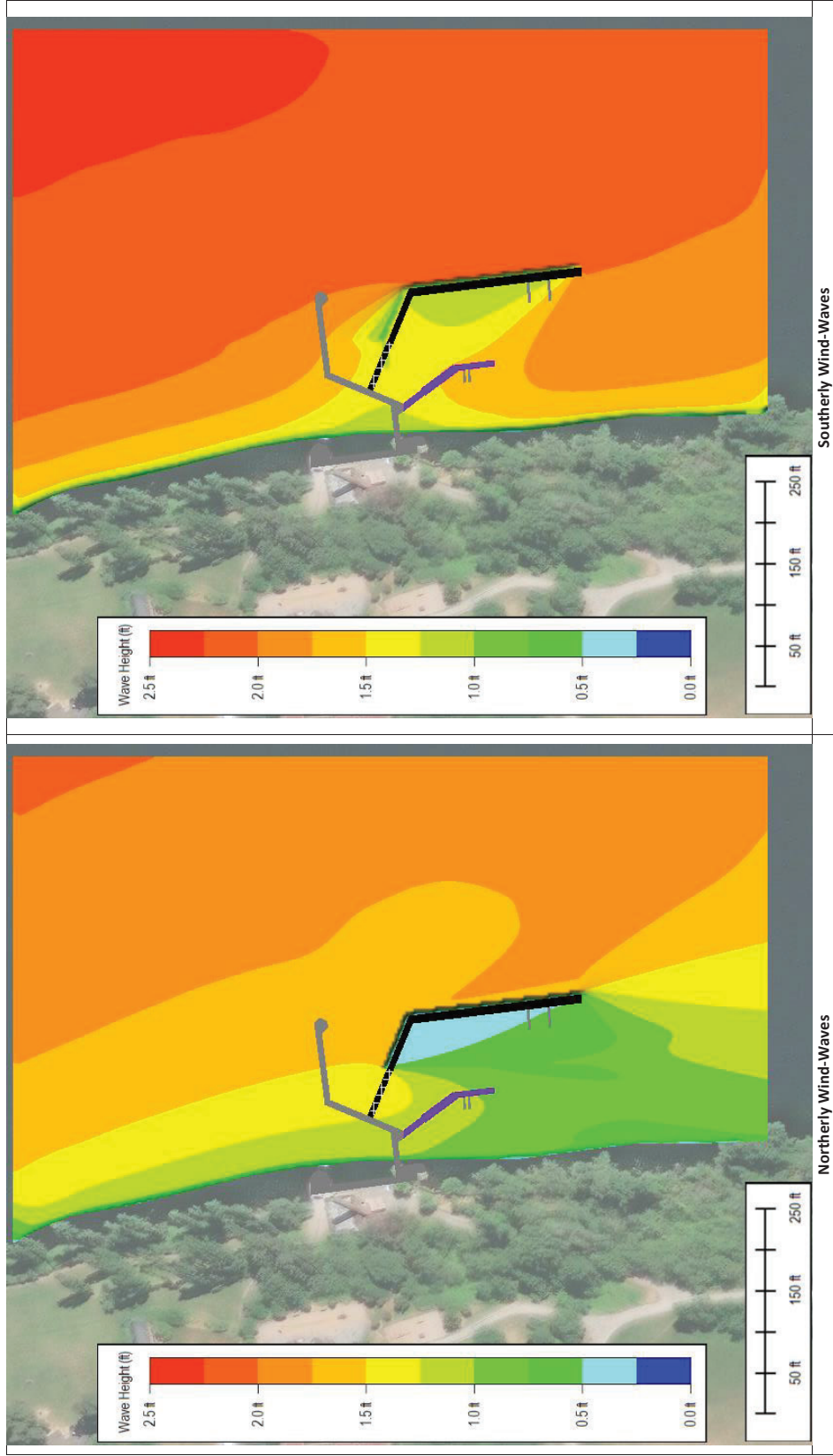


Figure 8: Plan View of Resulting 100-year Significant Wind-Wave Heights for Option 2: Current design extended (no dog leg): 210.5' x 10' x 4' draft main float – KT = 23 %

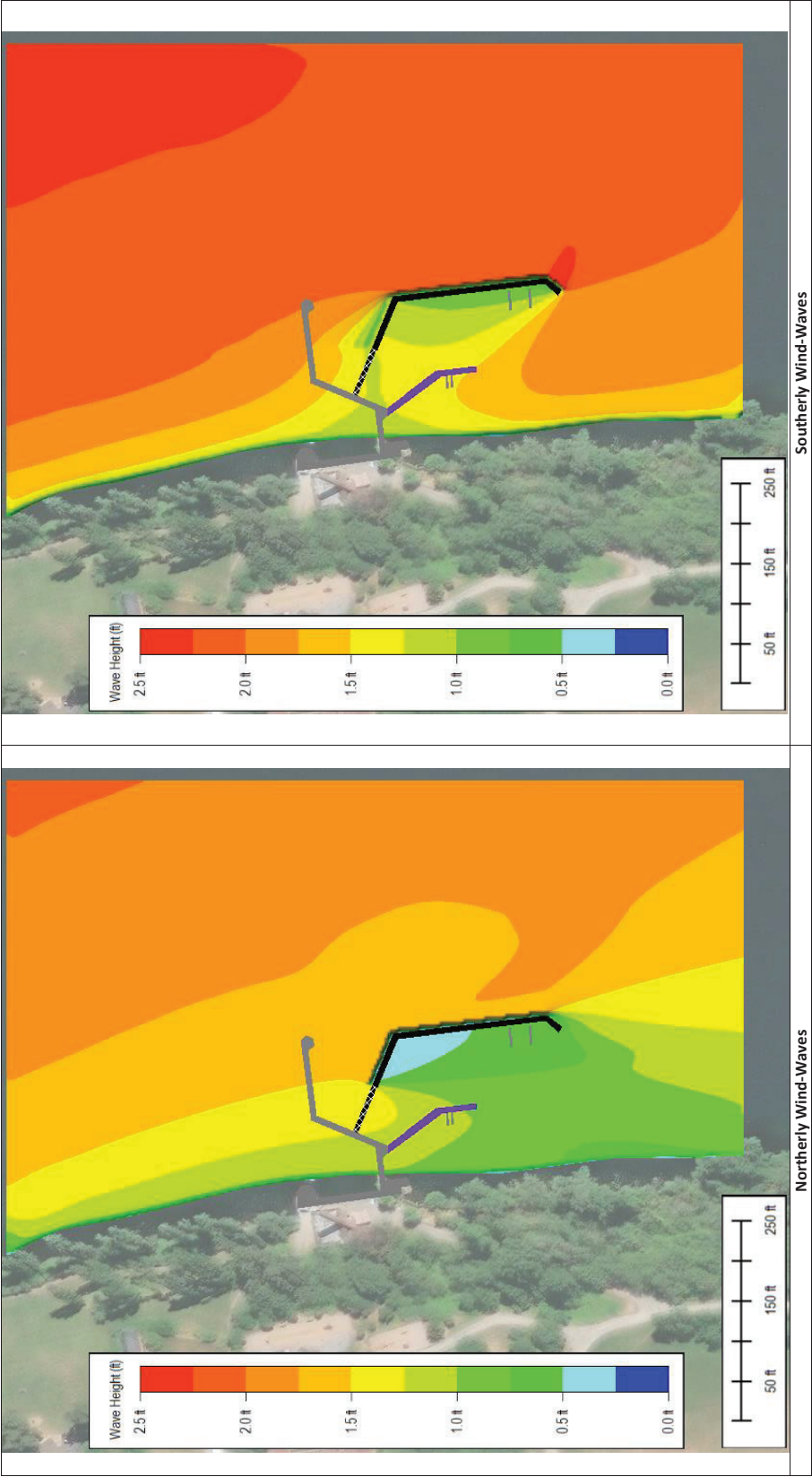


Figure 9: Plan View of Resulting 100-year Significant Wind-Wave Heights for Option 3: Narrower: 193' x 8' x 4' draft main float - KT = 28 %

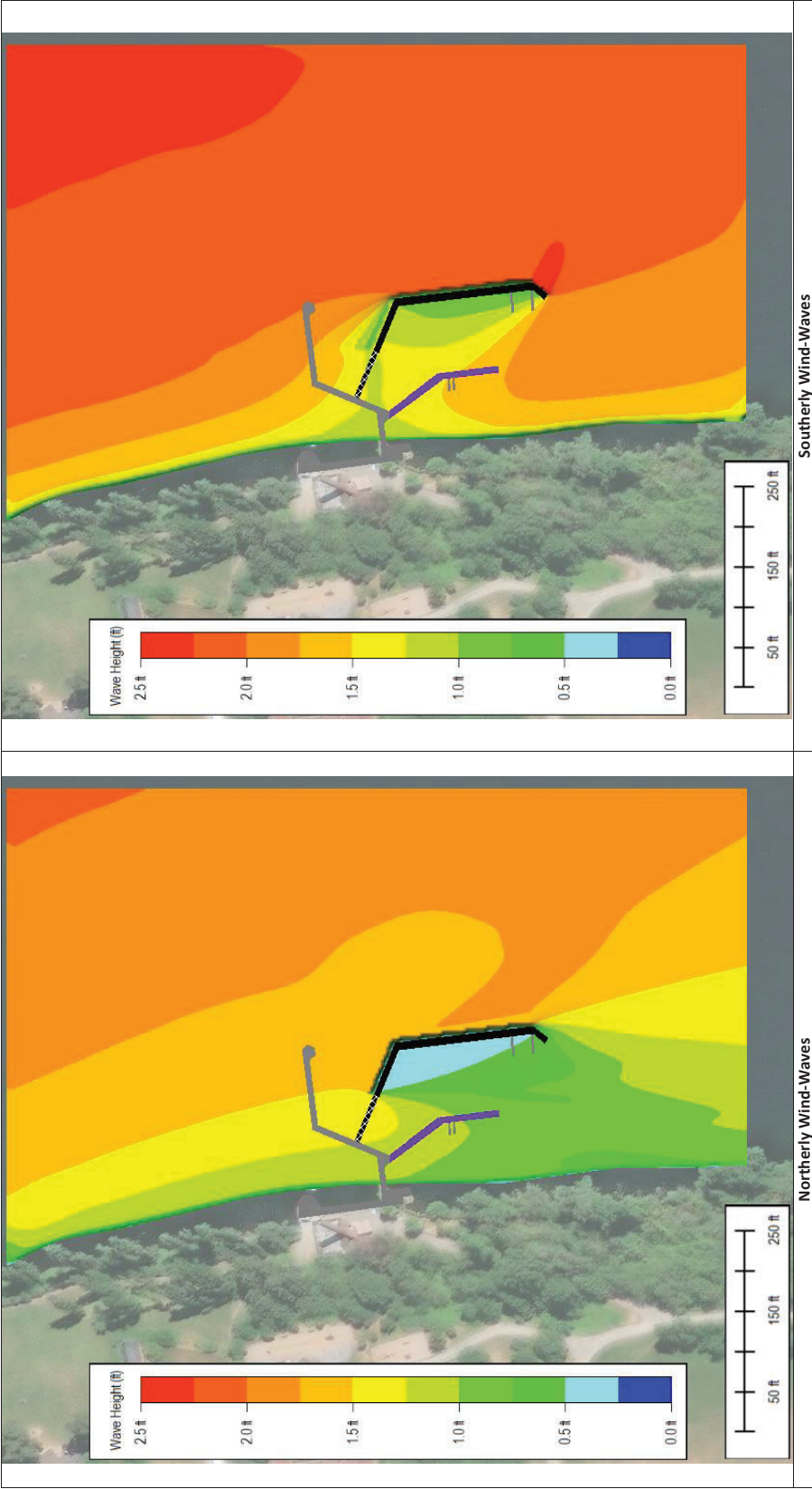


Figure 10: Plan View of Resulting 100-year Significant Wind-Wave Heights for Option 4: Shorter: 173' x 10' x 4' draft main float (inner float +25') – KT = 23 %

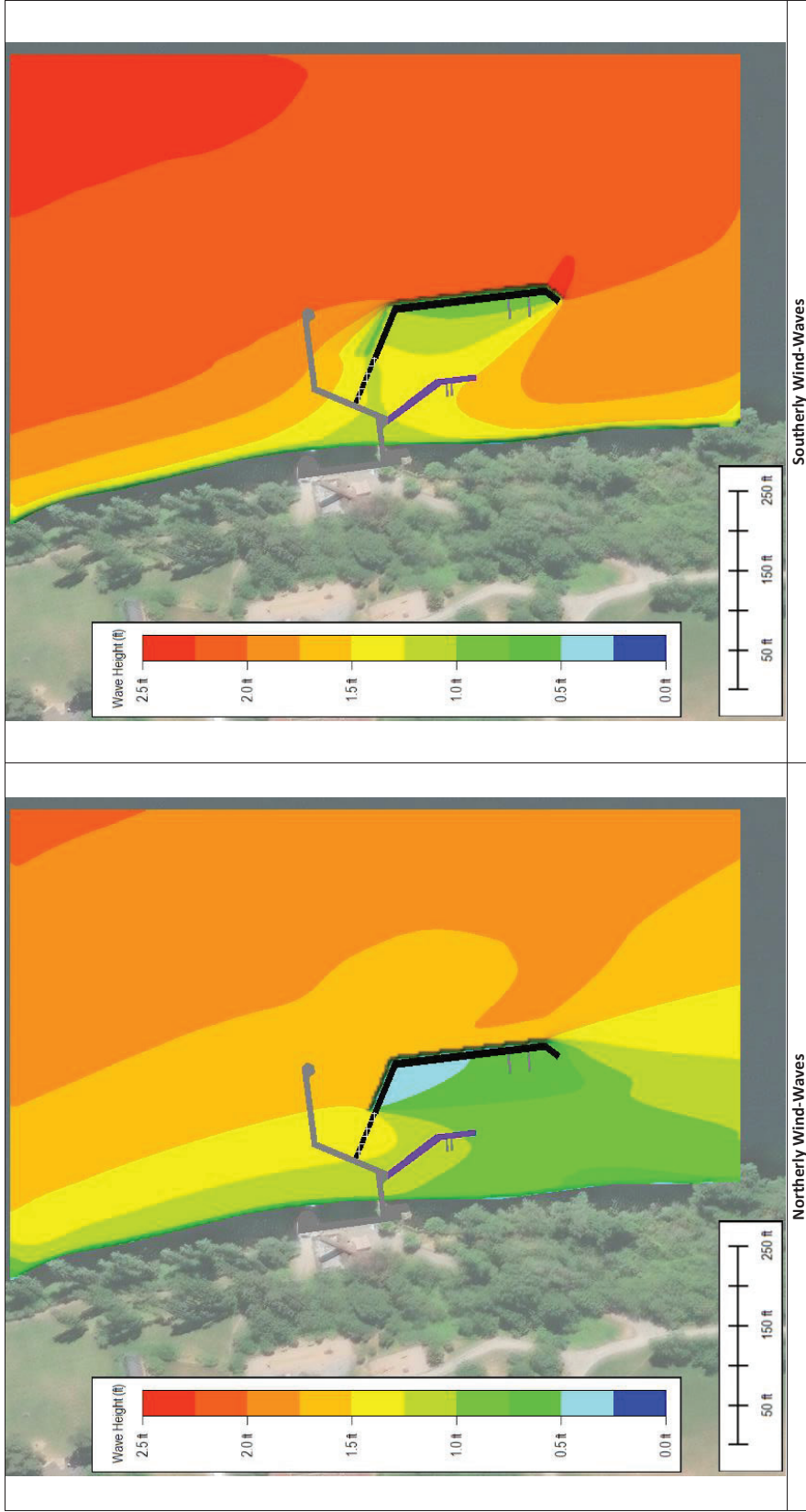


Figure 11: Plan View of Resulting 100-year Significant Wind-Wave Heights for Option 5: Lighter: 193' x 10' x 2' draft main float – KT = 28 %

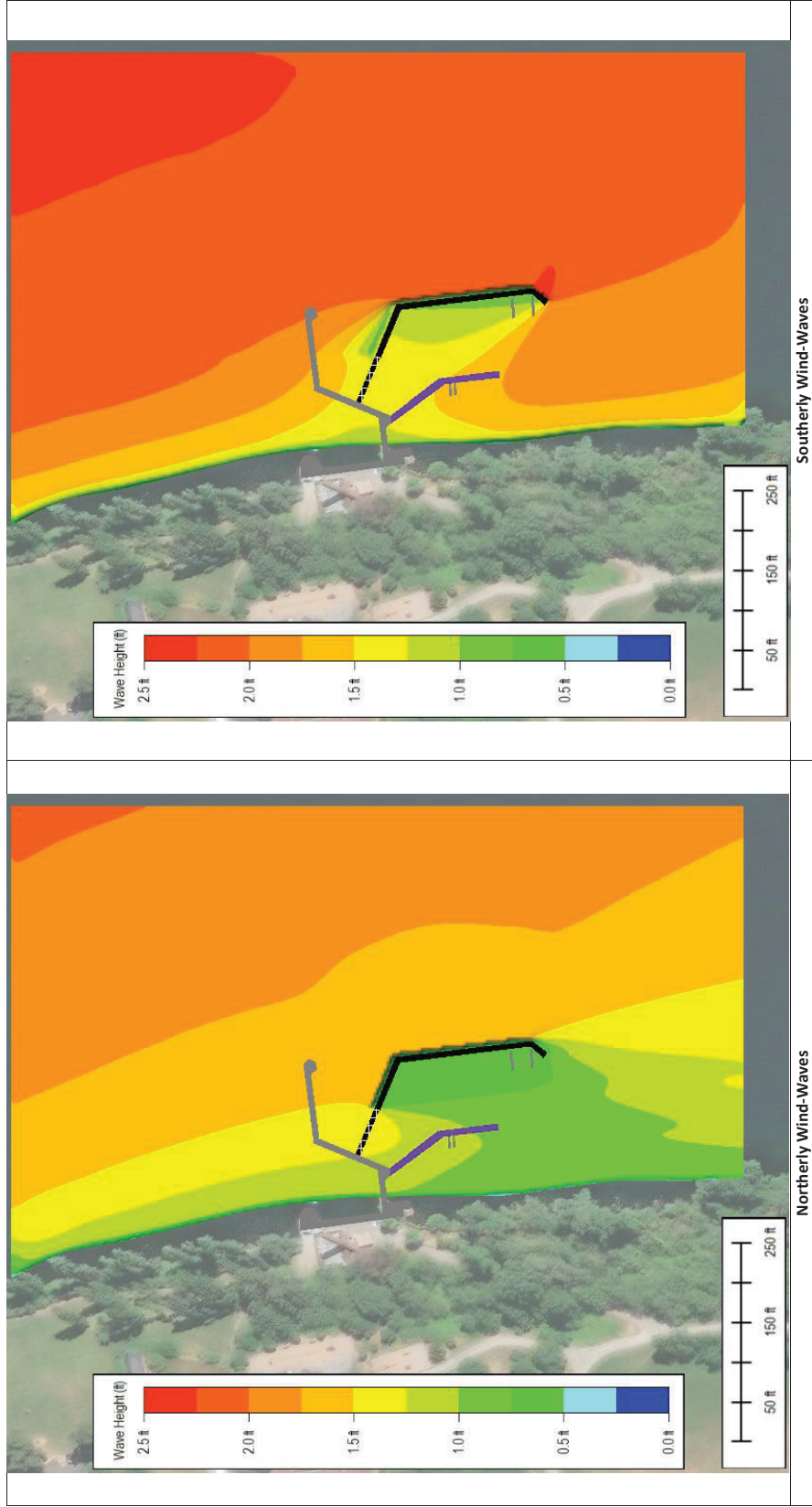


Figure 12: Plan View of Resulting 100-year Significant Wind-Wave Heights for Option 6: Minimum: 173' x 8' x 2' draft main float (inner float +25') – KT = 35 %

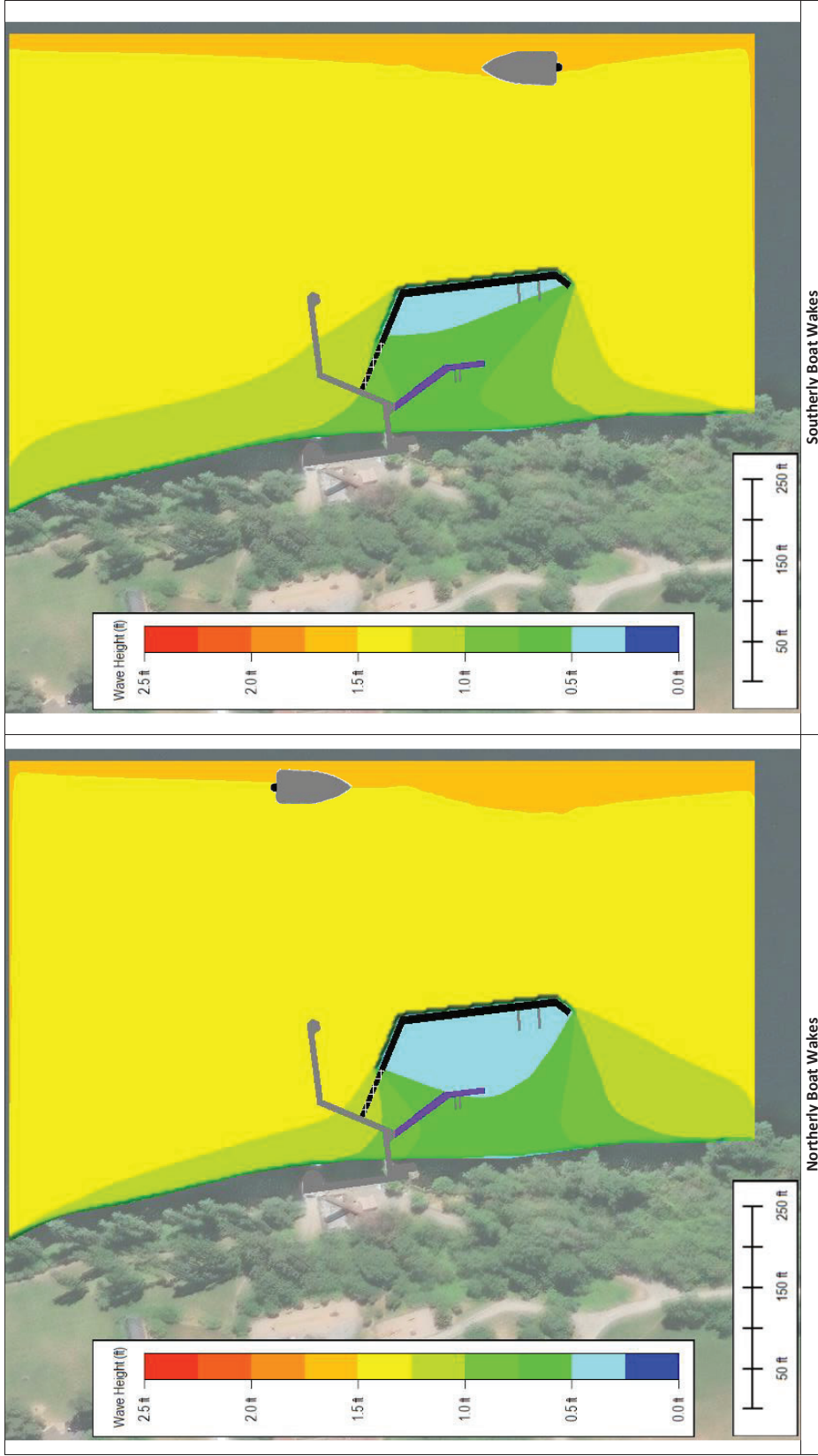


Figure 13: Plan View of Resulting Boat Wake Heights for Option 1: Current design: 193' x 10' x 4' draft main float – KT = 23 %

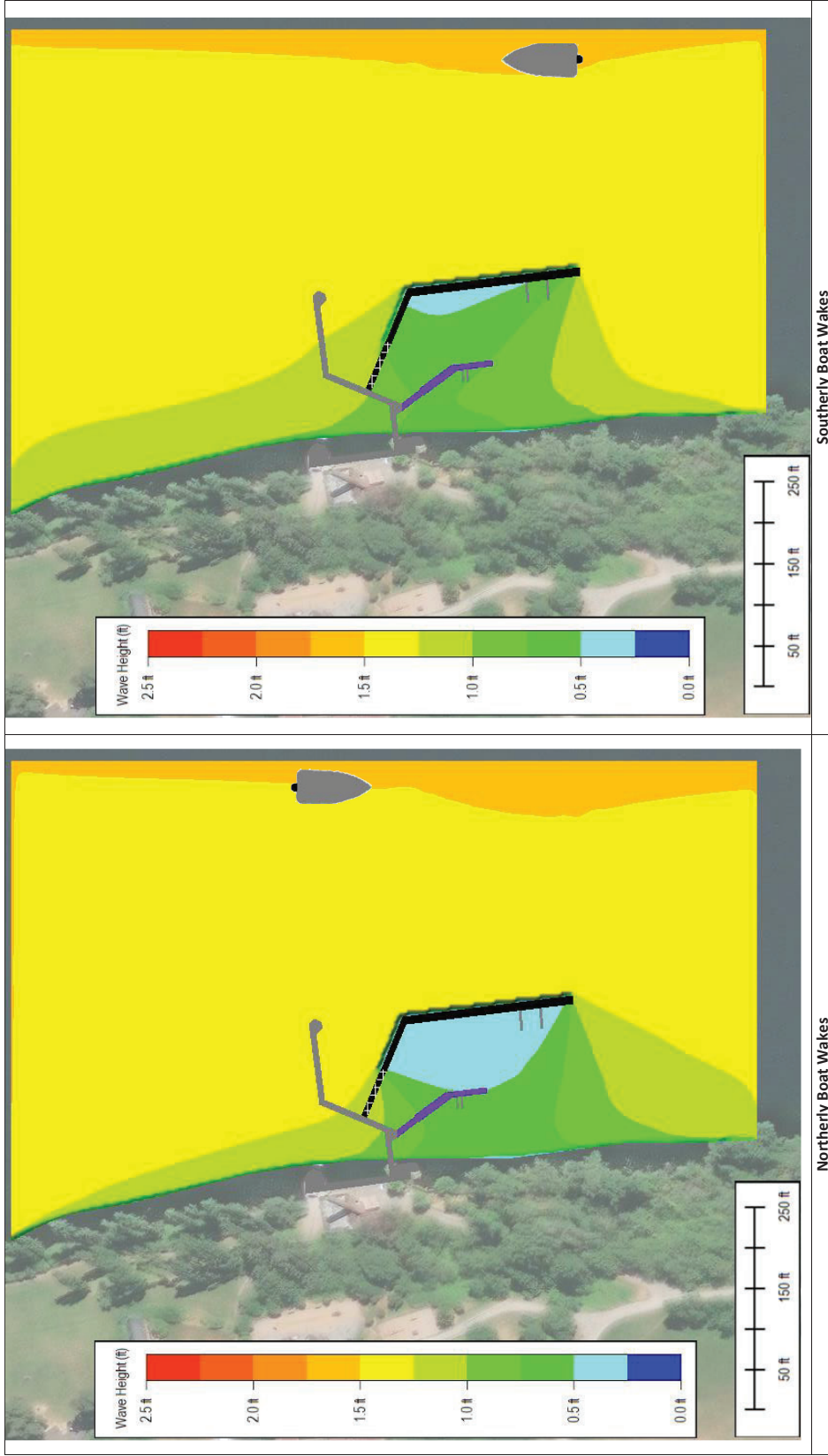


Figure 14: Plan View of Resulting Boat Wake Heights for Option 2: Current design: 210.5' x 10' x 4' draft main float – KT = 23 %

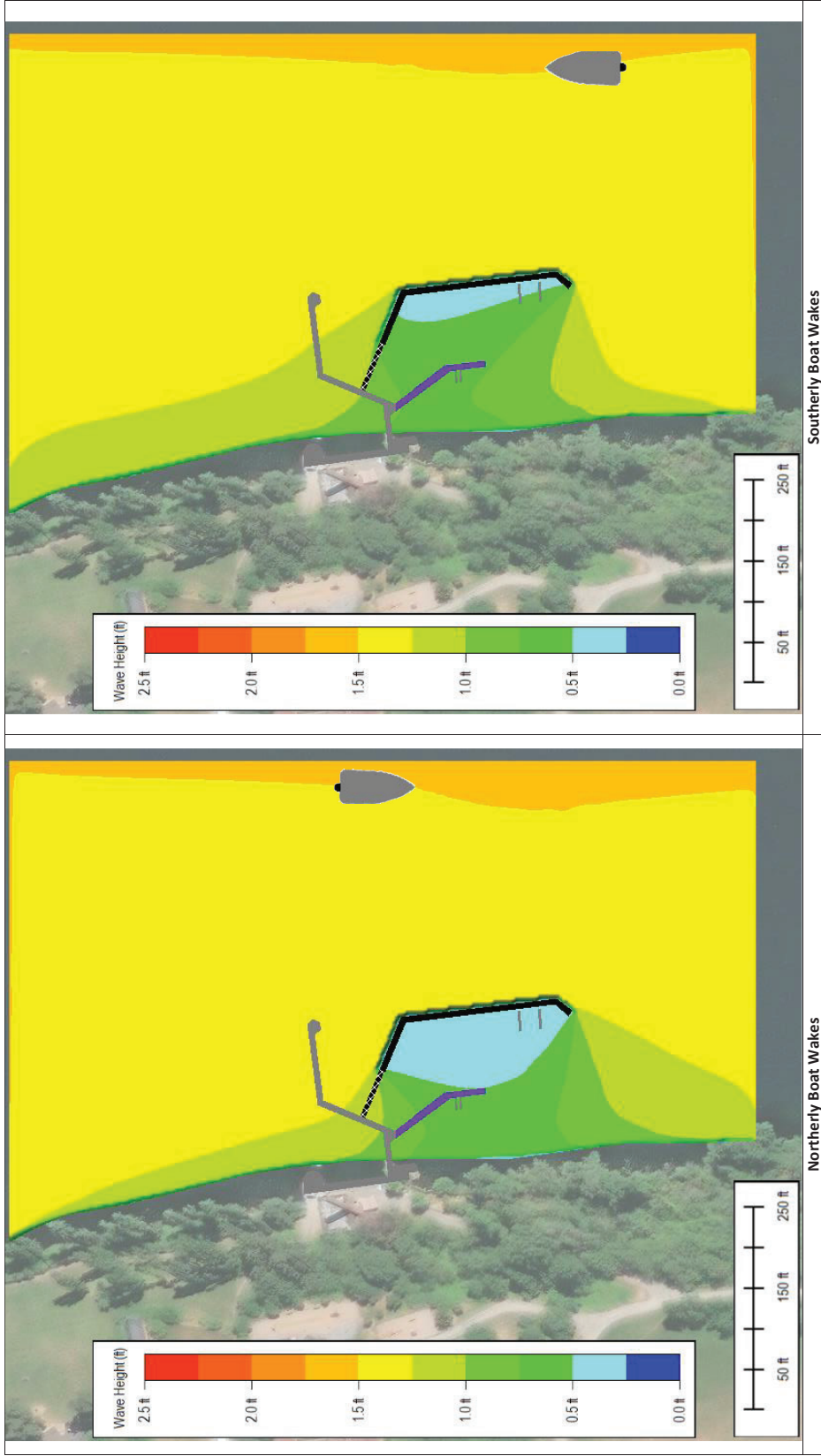


Figure 15: Plan View of Resulting Boat Wake Heights for Option 3: Narrower: 193' x 8' x 4' draft main float – KT = 28 %

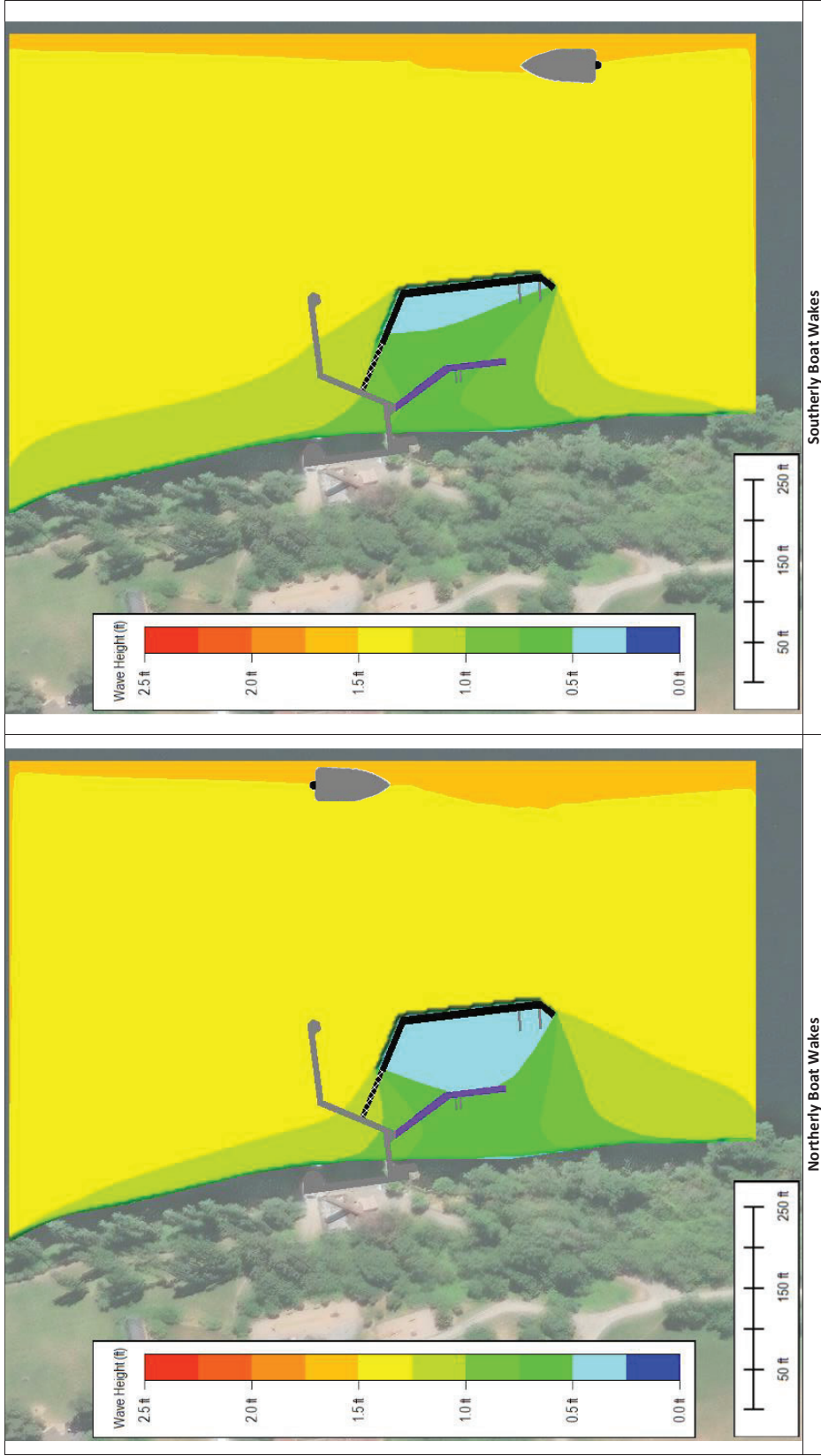


Figure 16: Plan View of Resulting Boat Wake Heights for Option 4: Shorter. 173' x 10' x 4' draft main float (inner float +25') - KT = 23 %

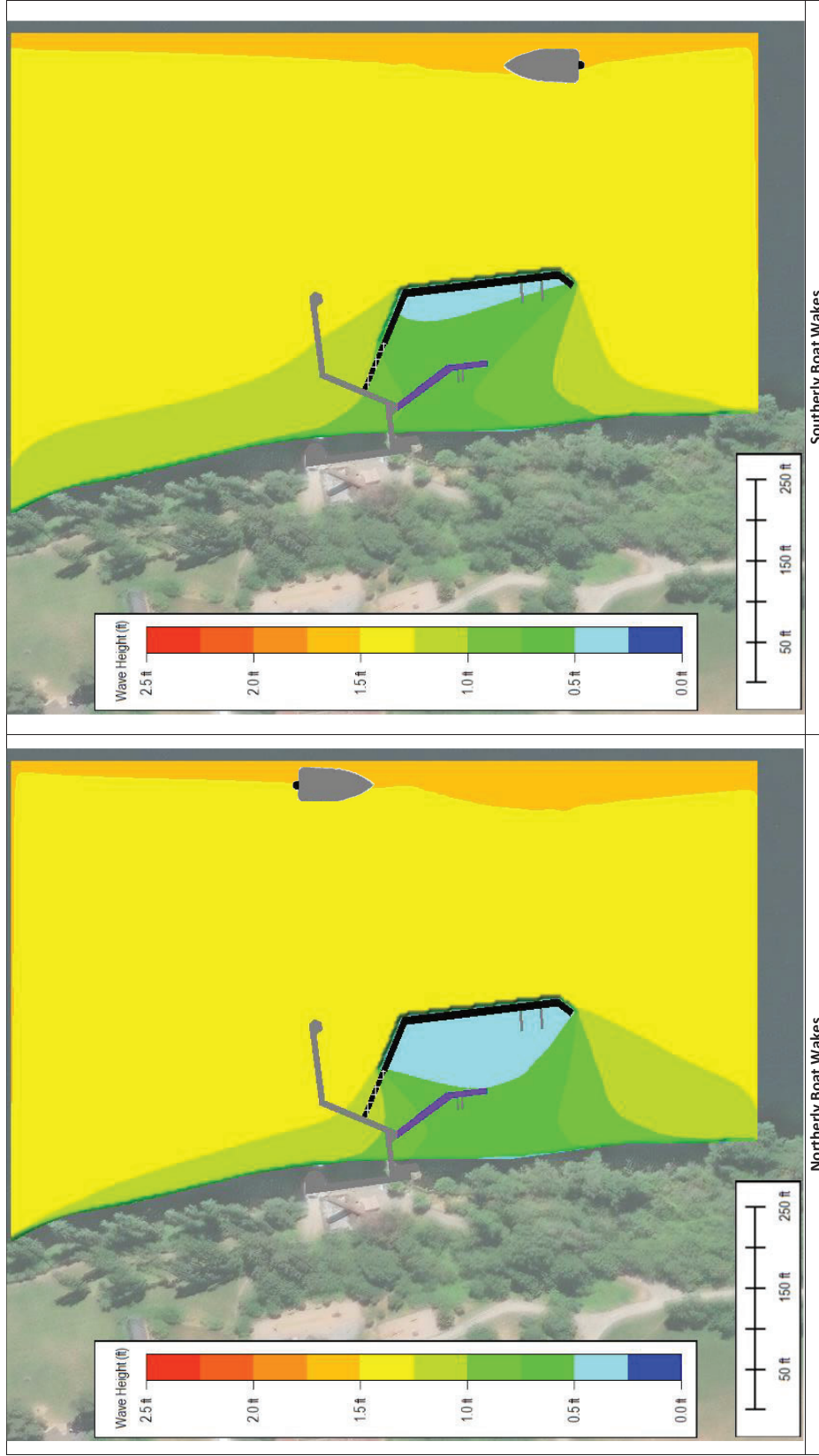


Figure 17: Plan View of Resulting Boat Wake Heights for Option 5: Lighter: 193' x 10' x 2' draft main float – KT = 28 %

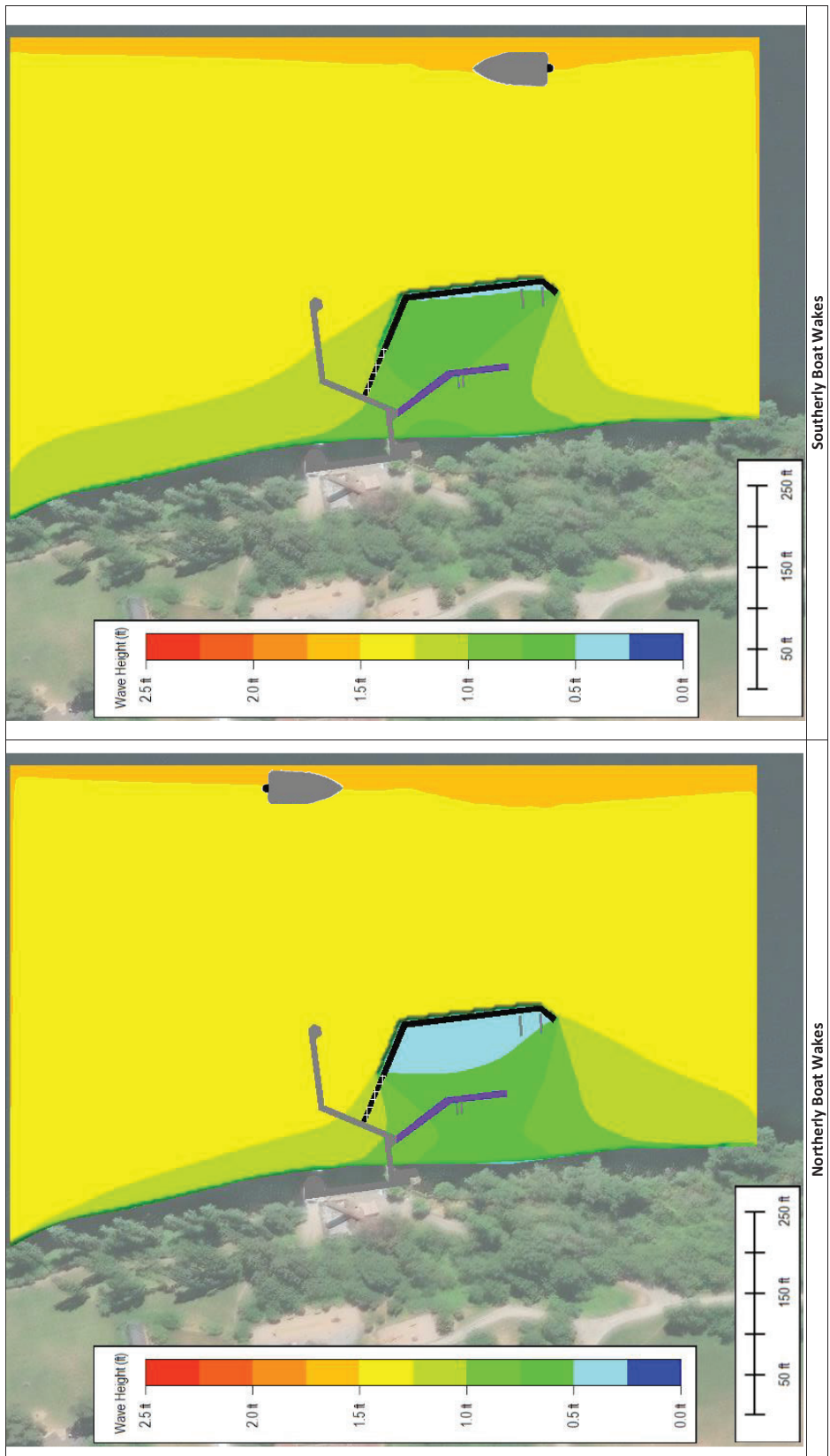


Figure 18: Plan View of Resulting Boat Wake Heights for Option 6: Minimum: 173' x 8' x 2' draft main float (inner float +25') – KT = 35 %

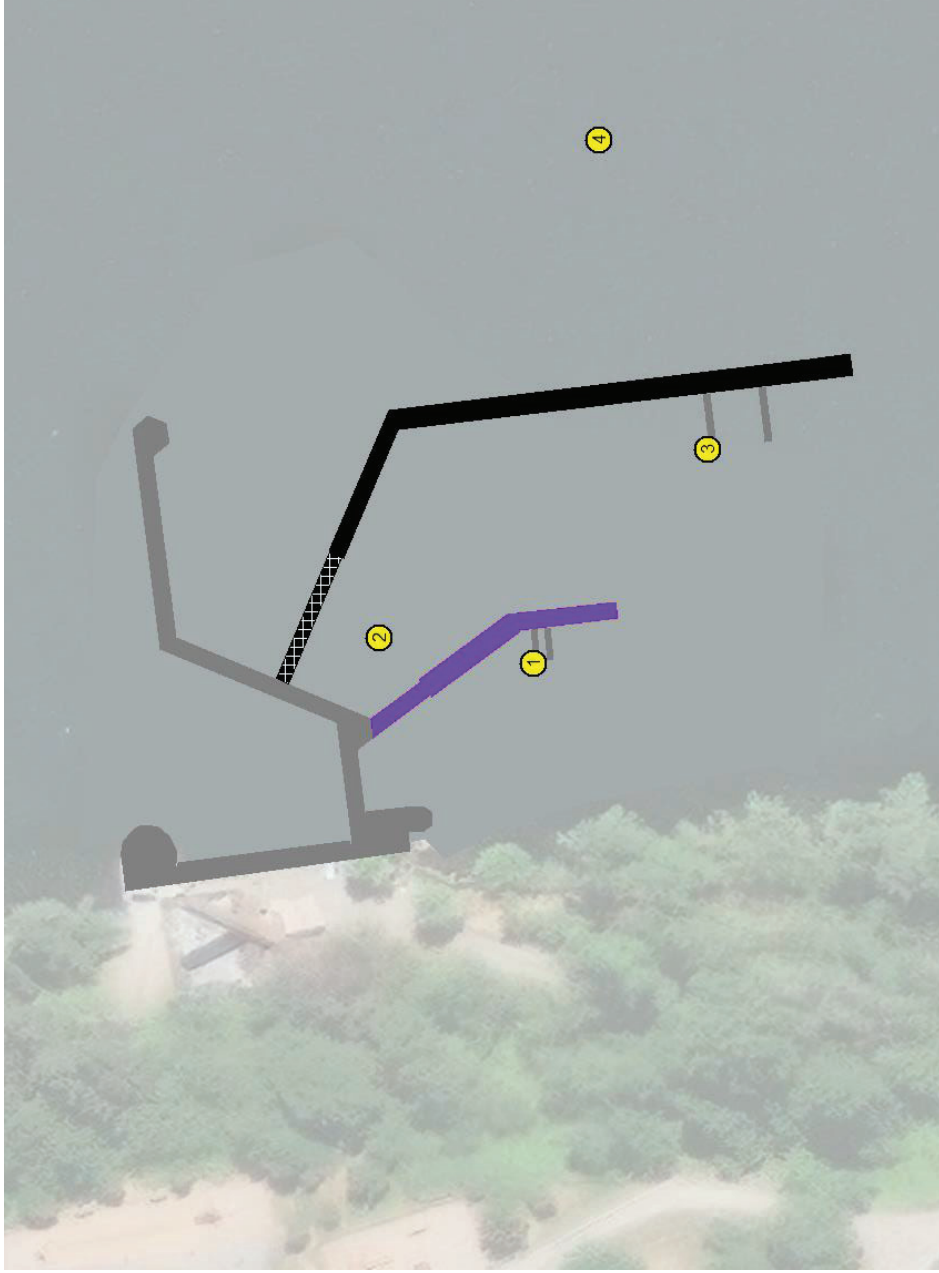


Figure 19: Location of Wave Height Extraction Points Inside the Marina