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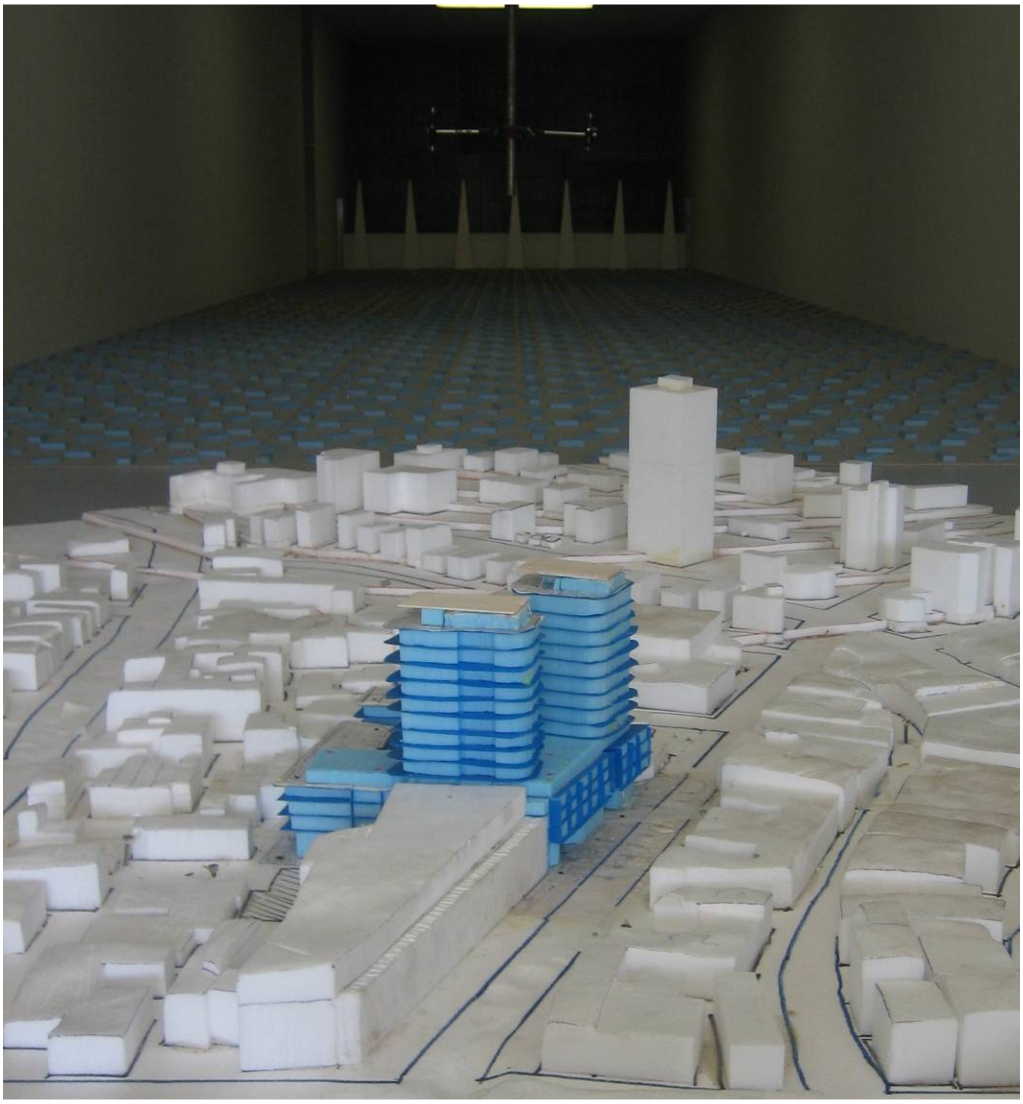

Pedestrian Wind Environment Study

for the proposed development located at

33 Cross St, Double Bay

February 4, 2009

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Sydney • Melbourne • Singapore • Dubai **www.windtech.com.au**
WINDTECH Consultants Pty Ltd: 19 Willis St, Wolli Creek NSW 2205 Australia ABN 72 050 574 037
T: (61.2) 9567 0722 **F:** (61.2) 9567 0733 **E:** reception@windtech.com.au

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1.0 Introduction

This report presents the results of a detailed investigation into the wind environment impact in relation to the development located at 33 Cross Street, Double Bay. Wind speed measurements were carried out using a 1:300 scale model of the proposed development. A surrounds model incorporating the local neighbouring buildings and land topography was placed around the model of the proposed development. The surrounds model extends to a radius of 375m from the site.

Testing was performed using Windtech's blockage tolerant boundary layer wind tunnel facility, which has a 3.0m wide work section and has a fetch length of 14m.

Peak gust wind speeds were measured and related to reference velocities at a height of 200m upstream of the proximity model. Wind speed velocity coefficients representing the local wind speeds are derived from the wind tunnel and are combined with the meteorological data for this region to provide the equivalent full-scale wind speeds. These wind speed measurements are compared with criteria for long and short duration stationary activities and for pedestrian comfort, based on annual maximum peak wind speeds and weekly maximum peak wind speeds.

The impact of the proposed development on the local surrounding area was also investigated by measuring wind conditions for the existing and future cases. For the existing wind conditions, a model of the existing building on the subject site was placed in the wind tunnel and tested.

The results of this study indicate that wind conditions at some of the outdoor areas of the proposed development will exceed the relevant criteria. The following treatments are recommended for the development:

- Retain the existing trees along the Cross Street frontage of the site.
- 1.2m high impermeable balustrades around some of the terraces and balconies.
- Densely foliating trees at on Level 5 rooftop areas as defined in architectural drawings.

The above treatments have been modelled and tested in the wind tunnel to verify their effectiveness. With these treatments included into the final design of the development, the wind conditions within and around the proposed development site will be acceptable for their intended uses.

The comparison of the existing and future wind conditions around the site indicates that there will be no adverse wind effects caused by the proposed development.

2.0 Model Description

2.1 Model of Study Buildings and Surrounds

Wind speed measurements were carried out using a 1:300 scale model of the development. A surrounds model incorporating the local neighbouring buildings and land topography was placed around the study building model. The surrounds model extends to a radius of 375m from the site. The impact of the proposed development on the local surrounding area was also investigated by measuring wind conditions for the existing and future cases. For the existing wind conditions, a model of the existing building on the subject site was placed in the wind tunnel and tested. Photographs of the wind tunnel model are presented in Figures 1a to 1f.

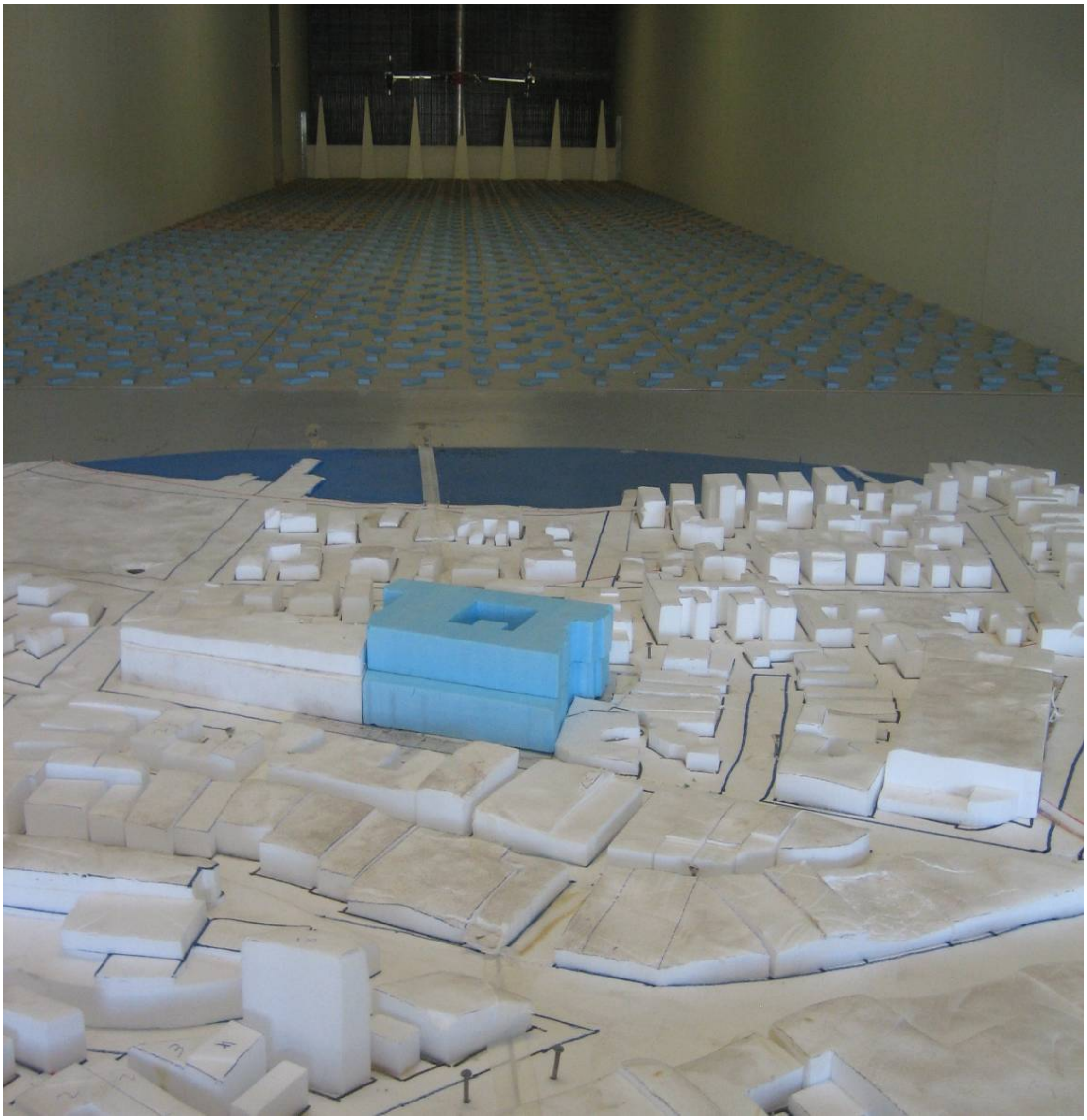


Figure 1a: Photograph of the Wind Tunnel Model (existing building on the subject development site) (view from the South)

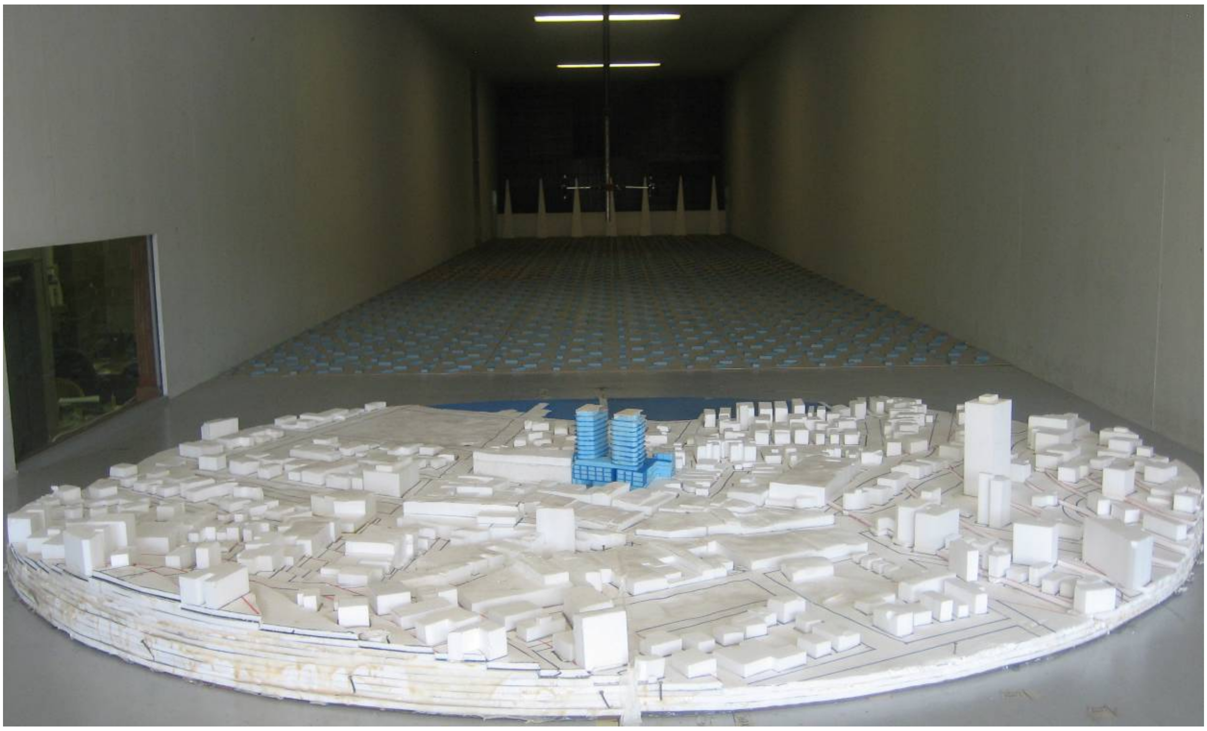


Figure 1b: Photograph of the Wind Tunnel Model
(proposed development model, view from the South)

Figure 1c: Photographs of Wind Tunnel Model
(proposed development model, view from the East)

Figure 1d: Photograph of the Model in the Wind Tunnel (proposed development model, view from the North)

Figure 1e: Photograph of the Model in the Wind Tunnel (proposed development model, view from the West)

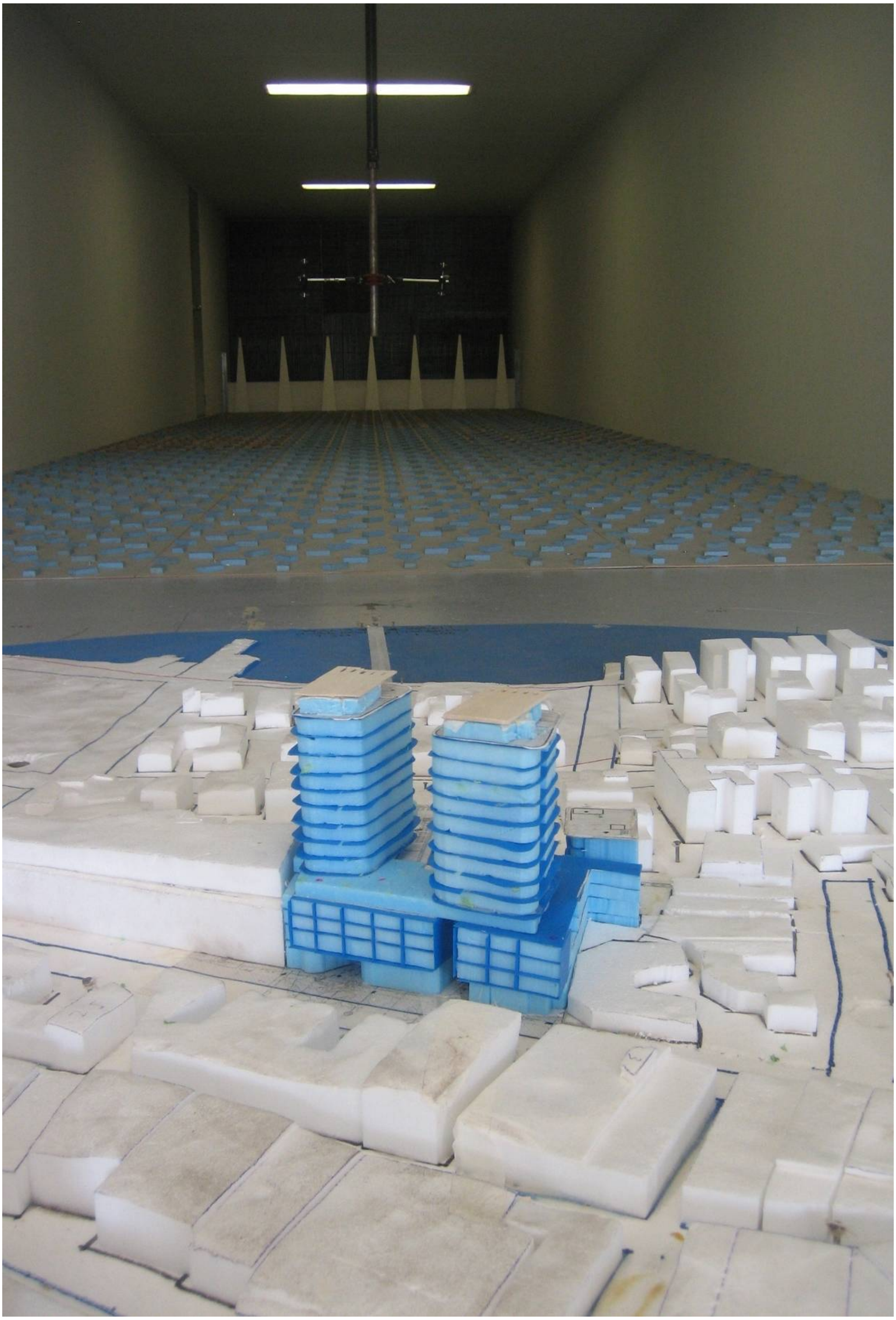


Figure 1f: Photograph of the Model in the Wind Tunnel (proposed development model, view from the South)

2.2 Wind Climate Model

The tower reference height used for this study is 51.8m, which is the height above ground for the residential towers. The boundary layer wind flows matched the model scale and the overall surrounding terrain characteristics beyond the 375m radius of the physical surrounds model tested in the wind tunnel for each wind direction tested. For the fetch beyond the extent of the surround model, the wind profiles are simulated based on the Deaves and Harris model (1978). The wind profile shape is calculated based on an analysis of the surrounding terrain for each wind direction tested. Figure 2 shows an aerial image of the site and surrounds for a radius of 40*h* from the site, where *h* is the height of the tower. Hence, for this project, the fetch length is 2070m. The terrain types indicated in Figure 2 are classified as open, suburban or urban.

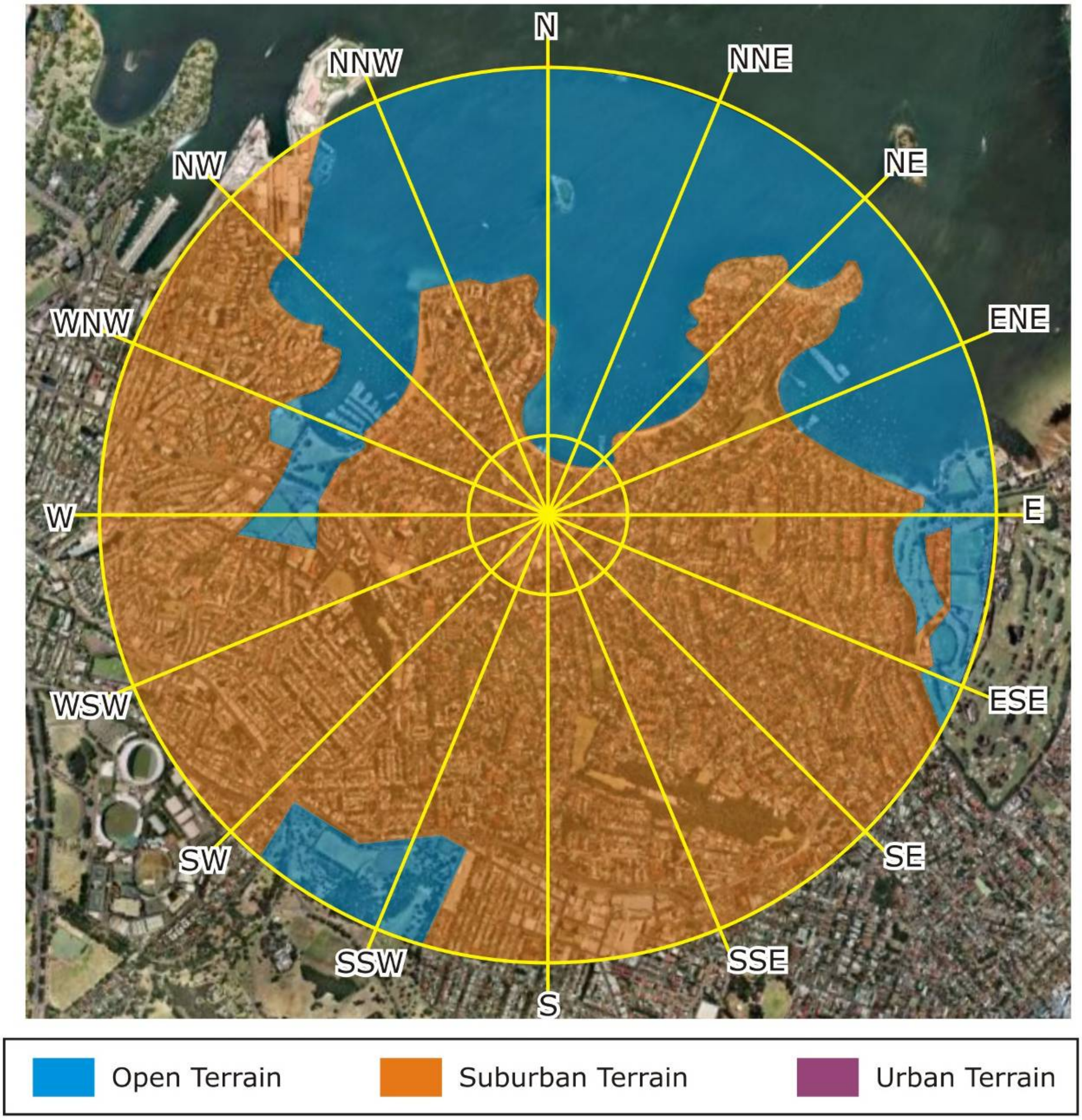


Figure 2: Aerial Image of the Site and Surrounds (2070m radius)

The length of each terrain type, and the distance each terrain type is from the site, is analysed for each wind direction tested. When the wind travels from one terrain type to another, the mean velocity profile does not change instantly. A lag occurs, and is measured as a distance by the following formula, which is adapted from Davenport et al (1997):

$$x_i = z_{0,r}\left[\frac{z}{0.3z_{0,r}}\right]^{1.25} \qquad (2.1)$$

where x_i is the lag length caused by the change in terrain type.

z is the height above ground.

$z_{0,r}$ is the larger of the two roughness lengths of the two terrain types (see Table 1).

The wind profile for each wind direction is calculated using the lag distance equation above, and the site terrain analysis data measured from the image shown in Figure 2.

For example, wind coming from the eqast-north-east, it is assumed that the approaching wind profile at the edge of the study zone (2070m from the site for this study) is the standard Deaves and Harris (1978) open terrain profile, since this is coming from over water, where the open terrain profile is most appropriate. The wind continues over the water until, approximately 1.2km from the site, the wind reaches the coastline and suburban terrain, where the Deaves and Harris (1978) suburban terrain profile is most appropriate. The wind profile begins to adapt from the open terrain profile to the suburban terrain profile. However, by the lag distance equation, at a height of 100m above ground, the profile requires 2505m to fully change to the standard Deaves and Harris (1978) suburban terrain profile. Hence, by the time the wind reaches the site, at a height of 100m above ground, the profile is 48% developed into the suburban wind profile from the open wind profile. At 51.8m above ground (the reference height of the development used for this study) it is 92% developed into the suburban terrain profile. The wind profile plot in Appendix B for wind angle 67.5 shows that at the lower heights the profile is fully adapted into the suburban profile, and at the higher heights it is still adapting into the suburban profile from the open profile.

The wind profiles used for this study are shown in Appendix B of this report for each wind direction tested.

Table 1: Mean and Gust Terrain and Height Multipliers and Turbulence Intensity at Building Height, and the Corresponding Roughness Length for the Standard Deaves & Harris Profiles (1978) (51.8m)

Terrain Description	$\overline{M}_{(z,cat)}$ at BH	$M_{(z,cat)}$ at BH	Turbulence Intensity	Roughness Length (m) $z_{0,r}$
Flat	0.85	1.25	0.127	0.002
Open	0.76	1.18	0.150	0.020
Suburban	0.63	1.07	0.187	0.200
Dense Urban	0.43	0.91	0.268	2.000

The meteorological data for Sydney was analysed statistically from frequency of occurrence tables prepared by the National Climate Centre, which are based on continuous data collected at 3 hour intervals over 53 years, ending March 1992. Data was collected from the Sydney Airport Observation Office at a height of 6 metres.

The directional distributions of the statistical mean hourly wind speeds for Sydney, corrected for suburban terrain and a reference height of 200m, are shown in Figure 3.

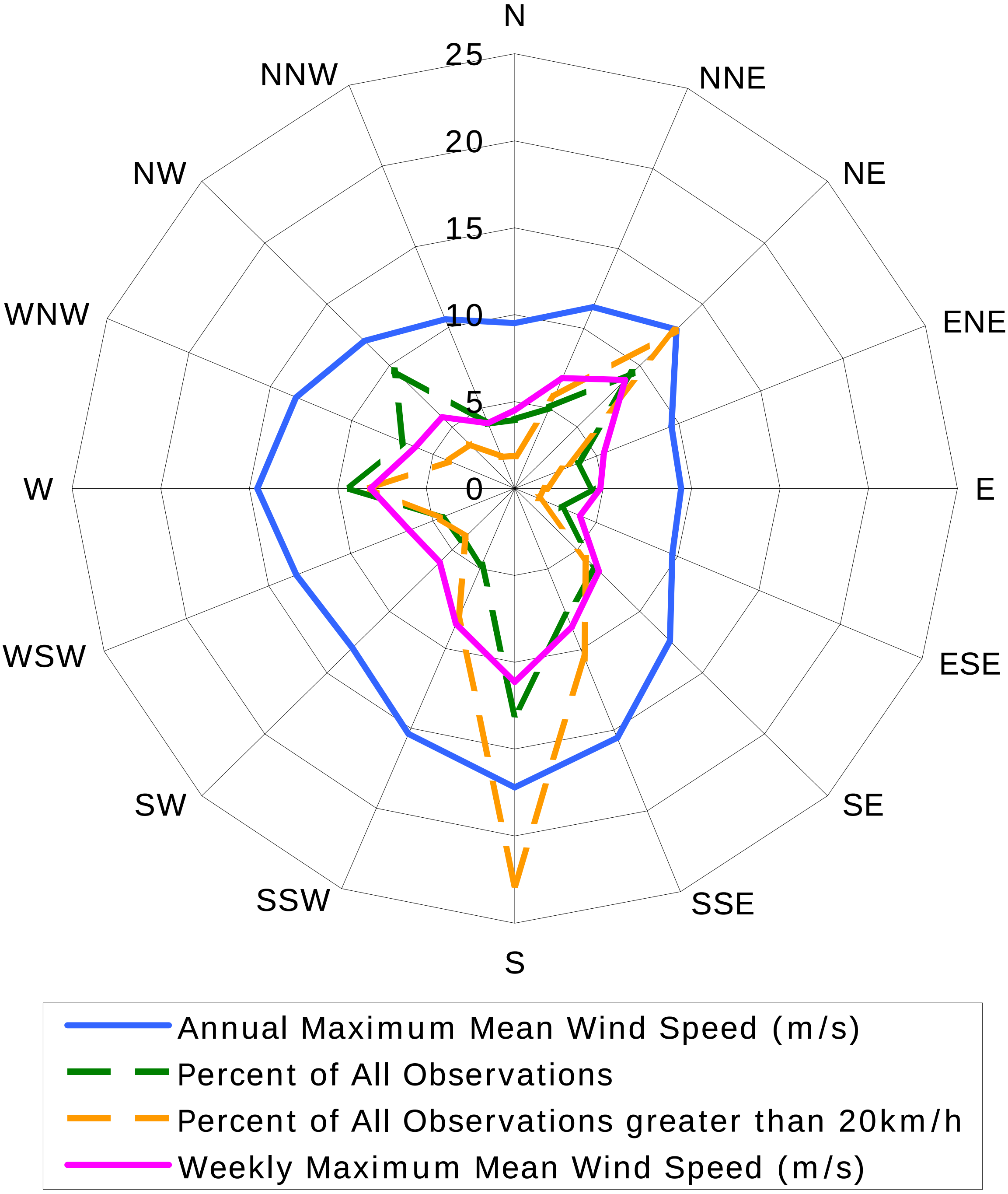


Figure 3: Maximum Mean Wind Speeds for Sydney (based on 10 minute means, obtained at Kingsford Smith Airport between 1939 and 1992, open terrain at 10m height)

3.0 Test Procedure

Testing was performed in Windtech's boundary layer wind tunnel facility. No correction is required for blockage effects. The mean free stream wind speed at the reference height in the tunnel is approximately 11.7m/s. For the annual reference wind speeds for Sydney, this corresponds to a velocity scale range of approximately 1:1.2 to 1:2.0. Hence the sample length in the model scale of 12.0 seconds is equivalent to a range of approximately 30 to 50 minutes in full-scale, which is suitable for this type of study.

A detailed analysis involving sixteen wind directions at 22.5 degrees intervals was carried out. This procedure provides comprehensive information about the wind environment to be expected for the various wind directions.

The freestream and test-location air currents were monitored using a pair of Dantec hot wire probe anemometers. The probe support was set vertically as much as possible. This ensures that the measured wind speeds are independent of wind direction along the horizontal plane. In addition, care was taken in the alignment of the probe wire and in avoiding wall-heating effects.

The output from both probes was obtained using a National Instruments 12-bit data acquisition card. The signal was low-pass filtered at 32 Hz and results in peak gust being the equivalent of the 2 to 3 second gust on which the criteria are based. A sample rate of 1000 samples per second was used, which is more than adequate for the given frequency band.

The mean and the maximum 3 second duration peak gust coefficients were obtained. The largest qualifying single peak was taken as the maximum gust velocity. To ensure that the largest measured peak is not a 'false' peak, the maximum peak would not qualify if it is more than 25% greater than the average of the second and third largest peaks. Any non-qualifying peak is replaced by the average of the second and third largest peaks.

For each of the sixteen wind directions, peak gust and mean wind speeds were measured at selected points at a full-scale height of approximately 1.5m and were normalised by the mean value at a reference scale height of 200m up-wind of the model. The reference velocity measurements are used to relate the mean and peak wind speed measurements to actual mean and gust velocities, based on available meteorological data for Sydney.

The impact of the proposed development on the local surrounding area was also investigated by measuring wind conditions for the existing and future cases.

4.0 Environmental Wind Speed Criteria

The acceptability of wind in any area is dependent upon its use. For example, people walking or window-shopping will tolerate higher wind speeds than those seated at an outdoor restaurant. The following table, developed by Penwarden (1975), is a modified version of the Beaufort Scale, and describes the effects of various wind intensities on people. Note that the applicability column related to wind conditions occurring frequently (approximately once per week on average). Higher ranges of wind speeds can be tolerated for rarer events.

Table 2: Summary of Wind Effects on People (after Penwarden, 1975)

Type of Winds	Beaufort Number	Mean Wind Speed (m/s)	Effects
Calm, light air	1	0 - 1.5	Calm, no noticeable wind
Light breeze	2	1.6 - 3.3	Wind felt on face
Gentle breeze	3	3.4 - 5.4	Hair is disturbed, Clothing flaps
Moderate breeze	4	5.5 - 7.9	Raises dust, dry soil and loose paper - Hair disarranged
Fresh breeze	5	8.0 – 10.7	Force of wind felt on body
Strong breeze	6	10.8 – 13.8	Umbrellas used with difficulty, Hair blown straight, Difficult to walk steadily, Wind noise on ears unpleasant.
Near gale	7	13.9 – 17.1	Inconvenience felt when walking.
Gale	8	17.2 -20.7	Generally impedes progress, Great difficulty with balance.
Strong gale	9	20.8 – 24.4	People blown over by ***gusts***.

Lawson (1973) quotes that Beaufort 4 wind speeds (6 to 8m/s means) would be acceptable if it is not exceeded for more than 4% of the time; and a Beaufort 6 (11 to 14m/s means) as being unacceptable if it is exceeded more than 2% of the time.

4.1 Davenport's Criteria for Mean Wind Speeds

Davenport (1972) had also come up with a set of criteria in terms of the Beaufort Scale and for various return periods. The values presented in Table 3 below are based on a frequency of exceedance of once per week (a probability of exceedance of 5%).

Table 3: Criteria by Davenport (1972)

Classification	Human Activities	95 Percentile Maximum Mean (once per week)
Walking Fast	Acceptable for walking, main public accessways	7.5 m/s < *v* < 10 m/s
Strolling, Skating	Slow walking, etc.	5.5 m/s < *v* < 7.5 m/s
Short Exposure Activities	Generally acceptable for walking & short duration stationary activities such as window-shopping, standing or sitting in plazas.	3.5 m/s < *v* < 5.5 m/s
Long Exposure Activities	Generally acceptable for long duration stationary activities such as in outdoor restaurants & theatres and in parks.	3.5 m/s > *v*

4.2 Lawson's Criteria for Mean Wind Speeds

Later, Lawson (1975) came up with a set of criteria very similar to those of Davenport's. These are presented in Tables 4a and 4b, below.

Table 4a: Safety Criteria by Lawson (1975)

Classification	Human Activities	Annual Maximum Mean
Safety (all weather areas)	Accessible by the general public	15 m/s
Safety (fair weather areas)	Private outdoor areas such as balconies, terraces etc	20 m/s

Table 4b: Comfort Criteria by Lawson (1975)

Classification	Human Activities	95 Percentile Maximum Mean (once per week)
Business Walking	Objective Walking from A to B	8 m/s < *v* < 10 m/s
Pedestrian Walking	Slow walking, etc.	6 m/s < *v* < 8 m/s
Short Exposure Activities	Pedestrian Standing or sitting for a short time	4 m/s < *v* < 6 m/s
Long Exposure Activities	Pedestrian sitting for a long duration	4 m/s > *v*

4.3 Melbourne's Criteria for Peak Wind Speeds

Melbourne (1978) introduced a set of criteria for the assessment of environmental wind conditions. These criteria were developed for temperatures in the range from 10^{o}C to 30^{o}C and for people suitably dressed for outside temperature conditions. These criteria are based on peak gust wind speeds. Melbourne's criteria are outlined in Table 5 below. This set of criteria tends to be more conservative than criteria suggested by other researchers such as those indicated in Figure 4.

Table 5: Criteria by Melbourne (1978)

Classification	Human Activities	Annual Maximum Gust
Limit for safety	Completely unacceptable: people likely to get blown over.	*v* > 23m/s
Marginal	Unacceptable as main public accessways.	23 m/s > *v* > 16 m/s
Comfortable Walking	Acceptable for walking, main public accessways	16 m/s > *v* > 13 m/s
Short Exposure Activities	Generally acceptable for walking & short duration stationary activities such as window-shopping, standing or sitting in plazas.	13 m/s > *v* > 10 m/s

Table 5: Criteria by Melbourne (1978) (continued)

Classification	Human Activities	Annual Maximum Gust
Long Exposure Activities	Generally acceptable for long duration stationary activities such as in outdoor restaurants & theatres and in parks.	10 m/s > *v*

4.4 Comparison of the Various Wind Speed Criteria

The criteria mentioned in Table 5, as well as other criteria, are compared on a probabilistic basis in Figure 4, below.

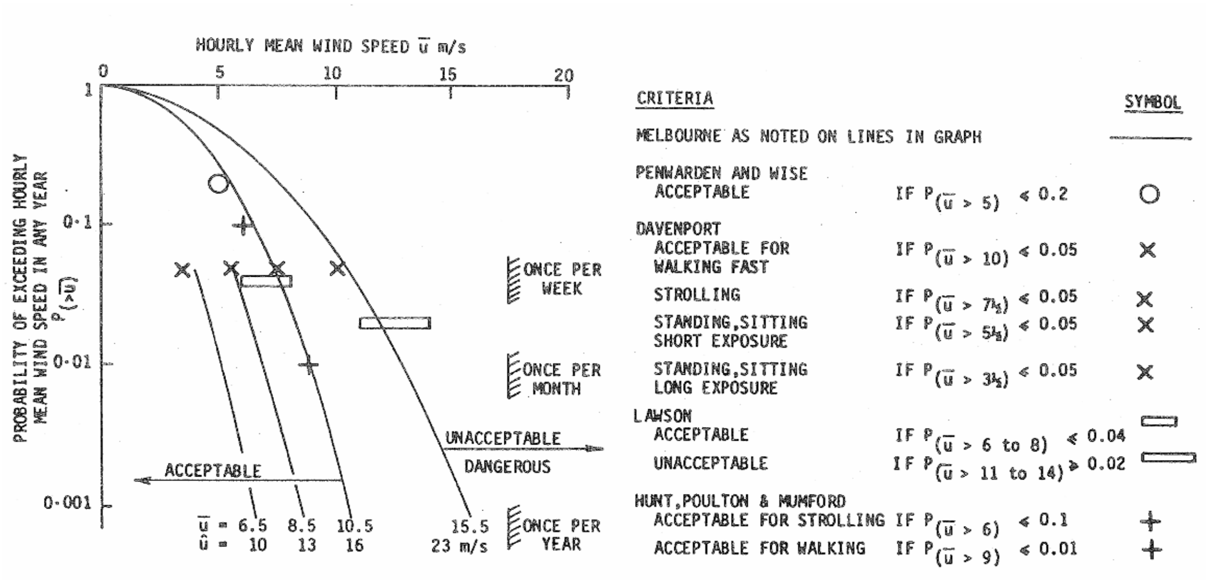


Figure 4: Comparison of Various Mean and Gust Wind Environment Criteria, assuming 15% turbulence and a Gust Factor of 1.5 (after Melbourne, 1978)

However, a comparative study presented by Ratcliff and Peterka (1990) based on measurements taken from a total of 246 locations in various urban situations tends to indicate that the criteria suggested by Melbourne (1978) can be considerably more conservative than the other criteria set out above. The results are in indicated in Figure 5. This agrees with our own observations (Rofail, 2007). This discrepancy in the criteria by Melbourne is due to the assumption of a fixed 15% turbulence intensity for all areas, which in our experience tends to be at the lower end of the range of turbulence intensities.

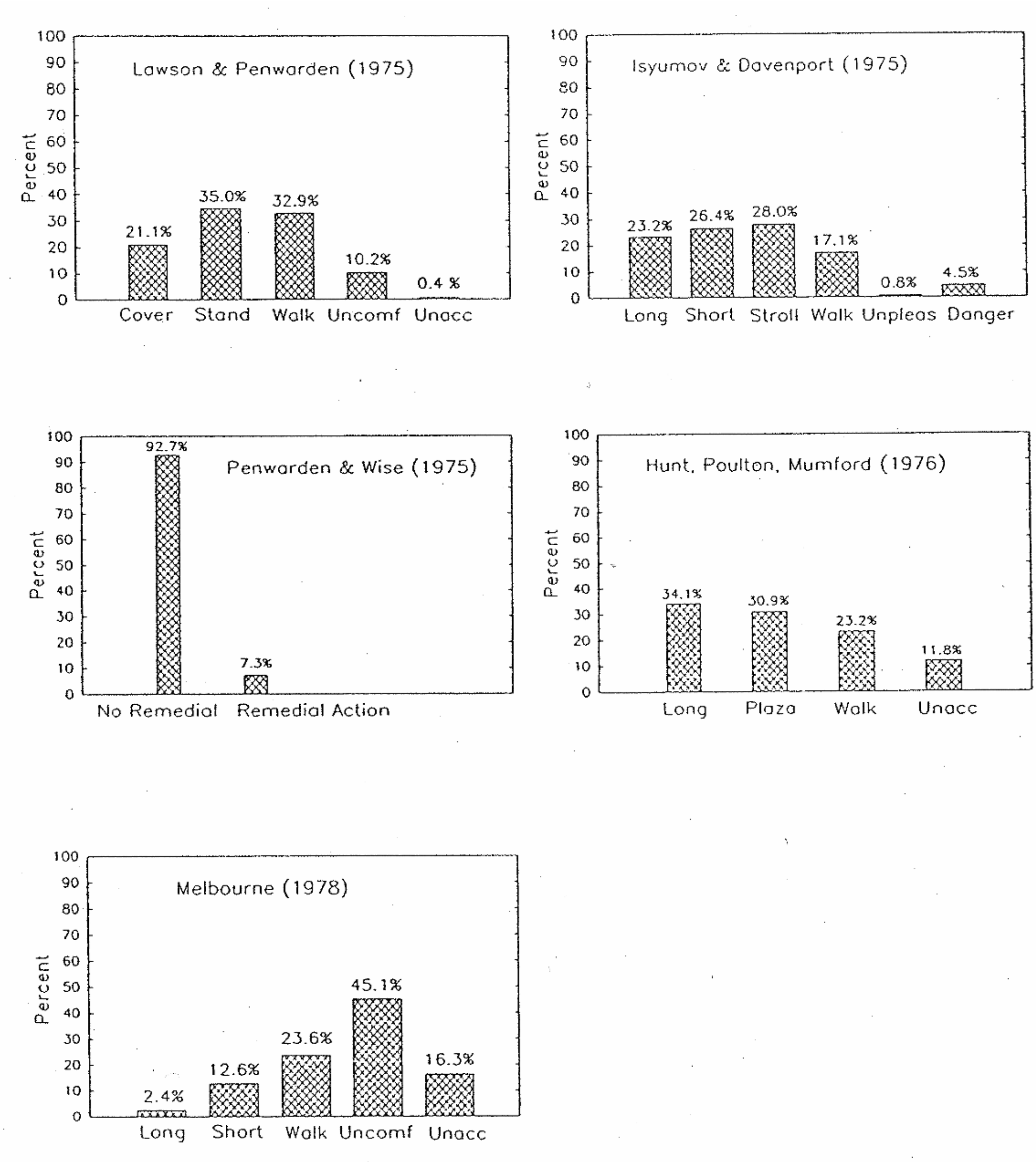


Figure 5: Distribution of Pedestrian Wind Comfort over Five Criteria for 246 locations examined in the Wind Tunnel (after Ratcliff & Peterka, 1990)

4.5 Criteria Used For This Study

For this study, the assessment of the local wind climate within and around the site has been based on two sets of criteria, as indicated in Figures 6a to 6f. These are described as follows:

- All areas of the development are compared to the Melbourne (1978) Safety Limit criterion of 23m/s for an annual maximum peak wind speed (see Table 5).
- Critical outdoor areas which are proposed for outdoor seating are compared against the Davenport (1972) short exposure criterion of 5.5m/s for GEM wind speeds (see Table 3).
- All other outdoor areas within and around the proposed development are compared against the Davenport (1972) comfortable walking criterion of 7.5m/s for GEM wind speeds (see Table 3).
- Private balconies and terraces are only compared against the Melbourne (1978) Safety Limit criterion of 23m/s for an annual maximum peak wind speed (see Table 5).

Note that the gust wind speeds, for use with the Davenport criteria, have been converted to a Gust Equivalent Mean (GEM) wind speed. The GEM is defined as the maximum of the following:

- Mean wind speed
- Gust wind speed divided by a gust factor of 1.85

In this study, we have used the abovementioned Davenport criteria in conjunction with the GEM defined above as this has proven over time and through field observations to be the most reliable indicator of pedestrian comfort. The most reliable source of data for field observation results are obtained when undertaking remedial wind environment studies.

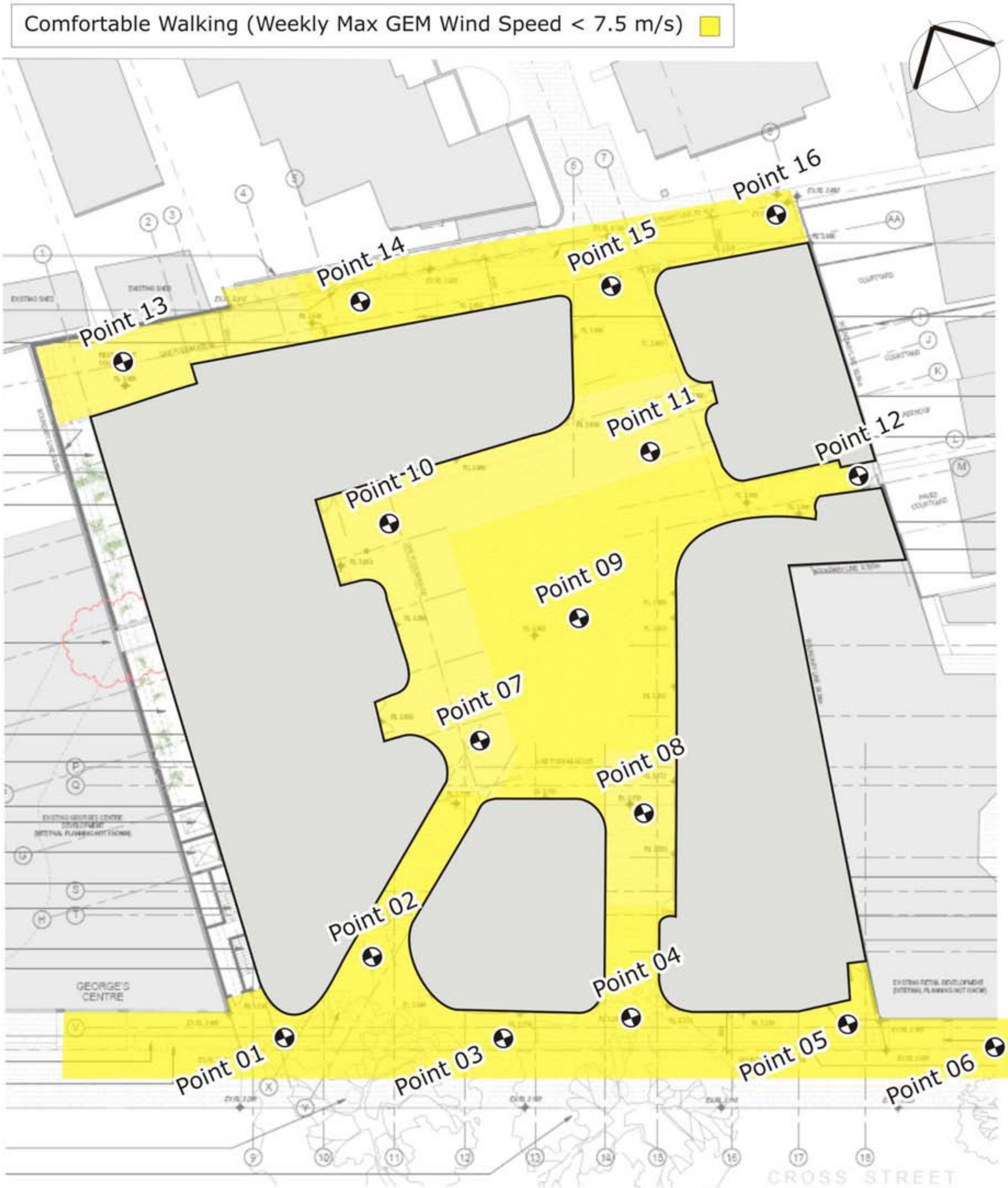


Figure 6a: Study Point Locations & Wind Comfort Criterion Zones Ground Level

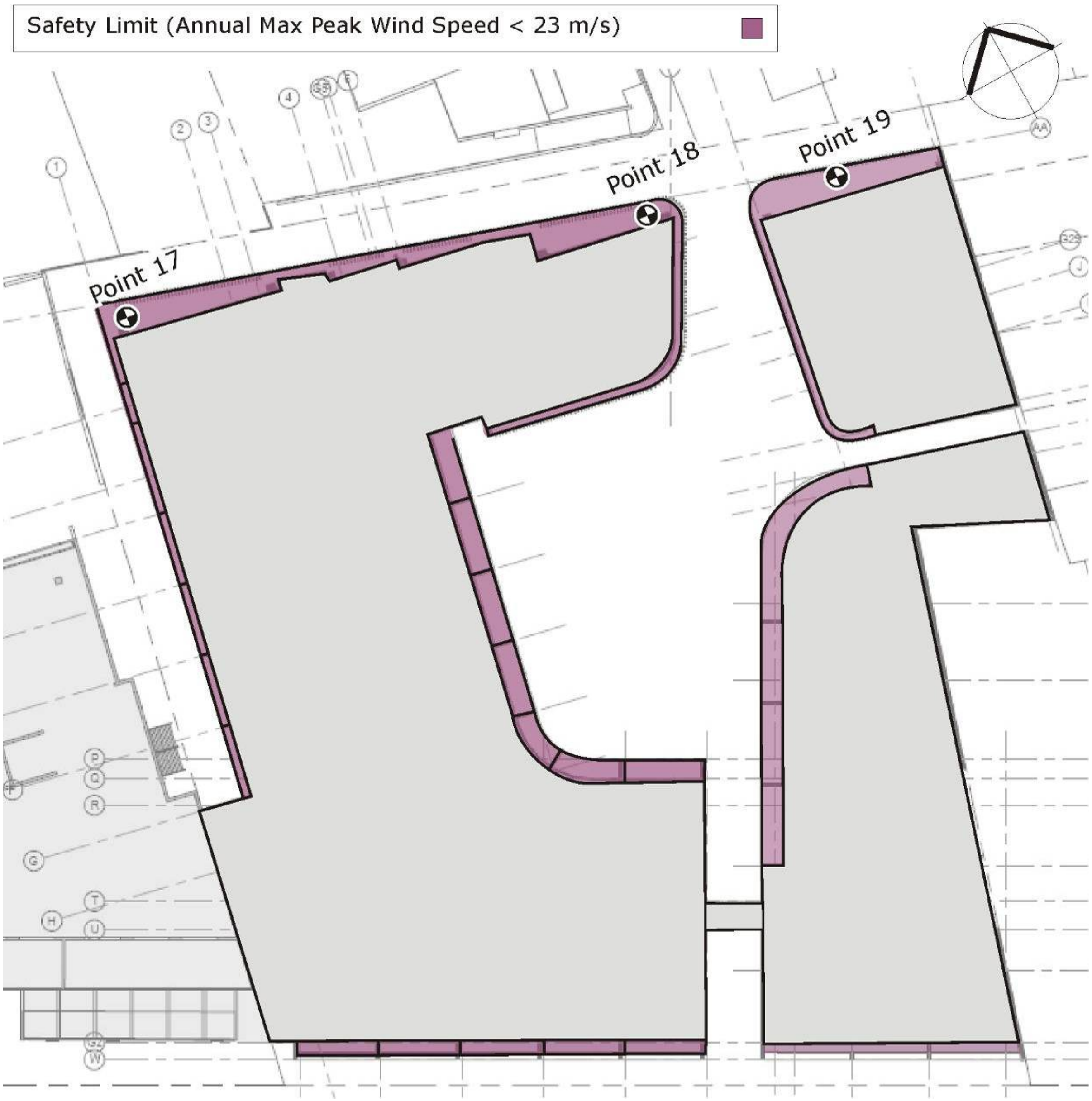


Figure 6b: Study Point Locations & Wind Comfort Criterion Zones Lower Level Balconies (up to Level 3)

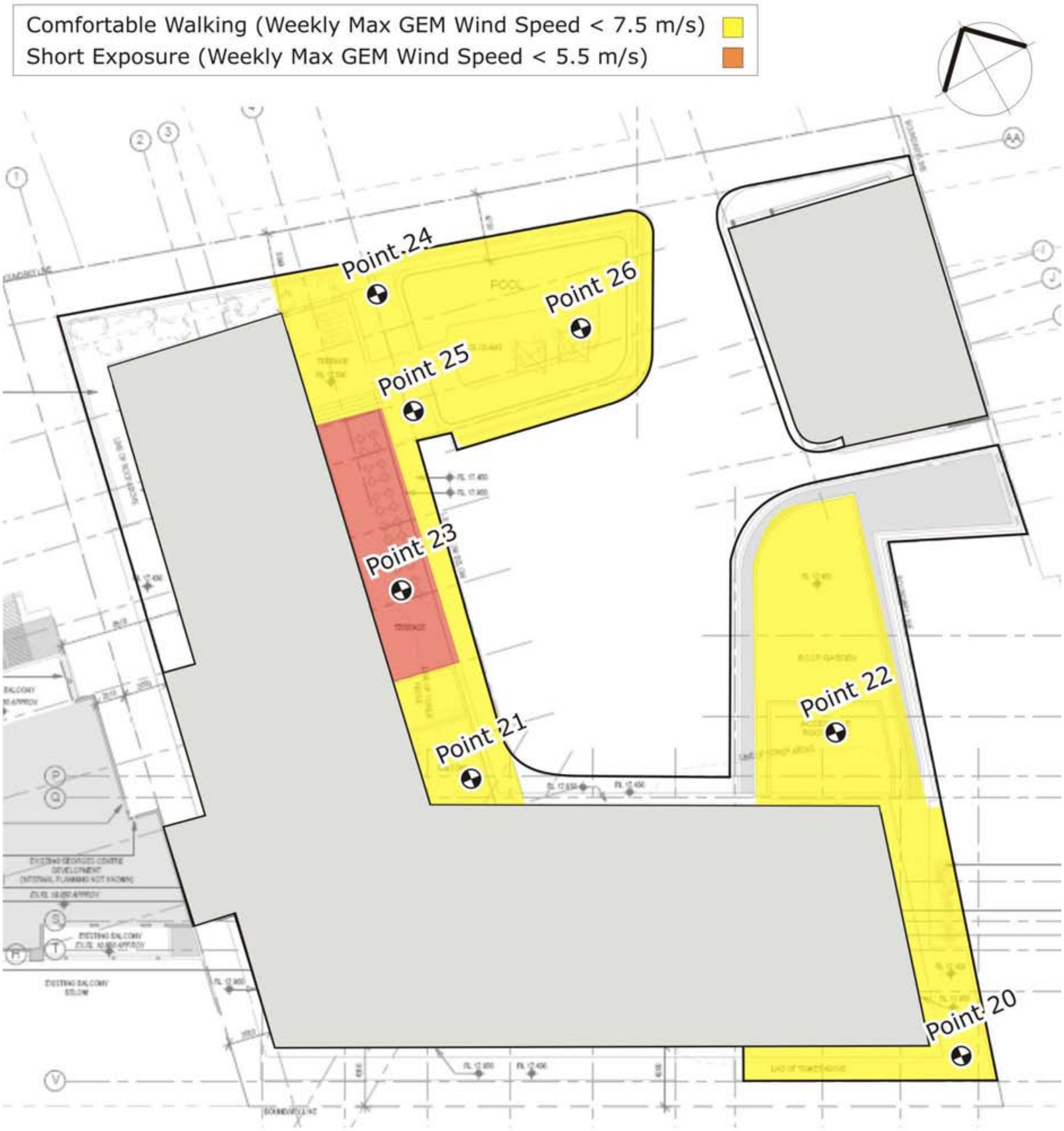


Figure 6c: Study Point Locations & Wind Comfort Criterion Zones Level 4

Figure 6d: Study Point Locations & Wind Comfort Criterion Zones Level 5

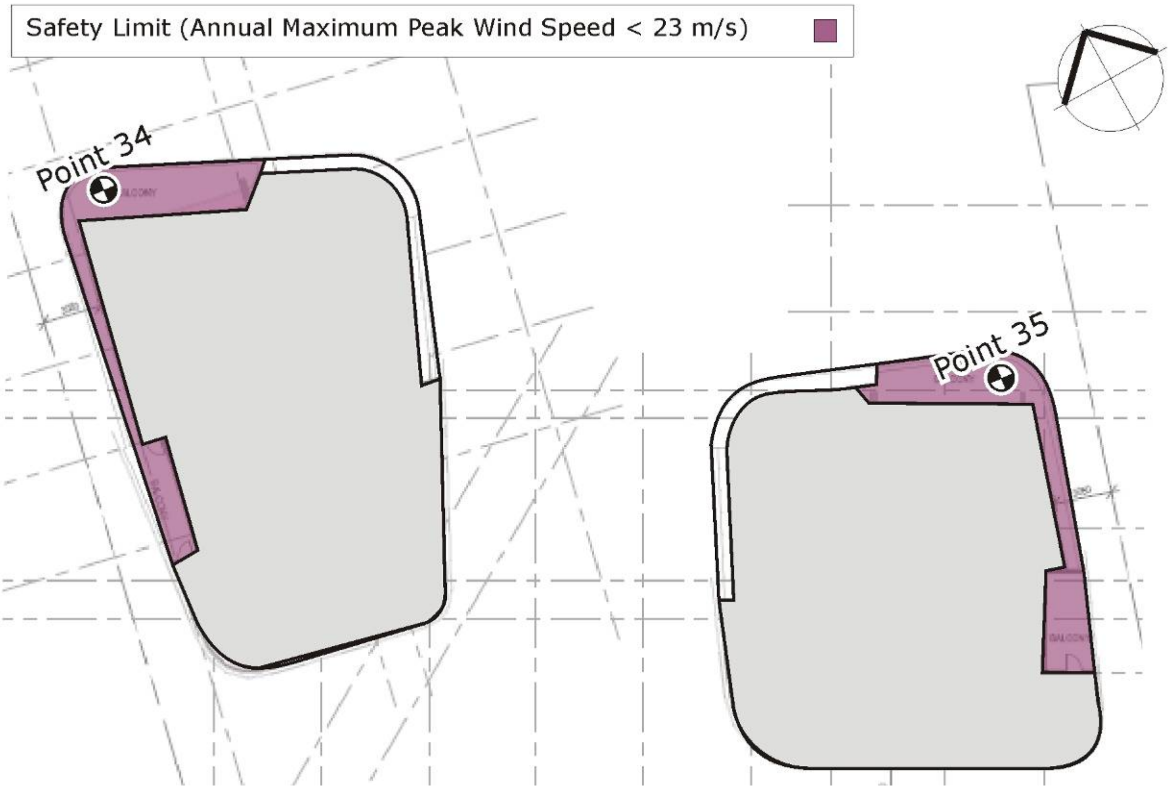


Figure 6e: Study Point Locations & Wind Comfort Criterion Zones Typical Private Balconies

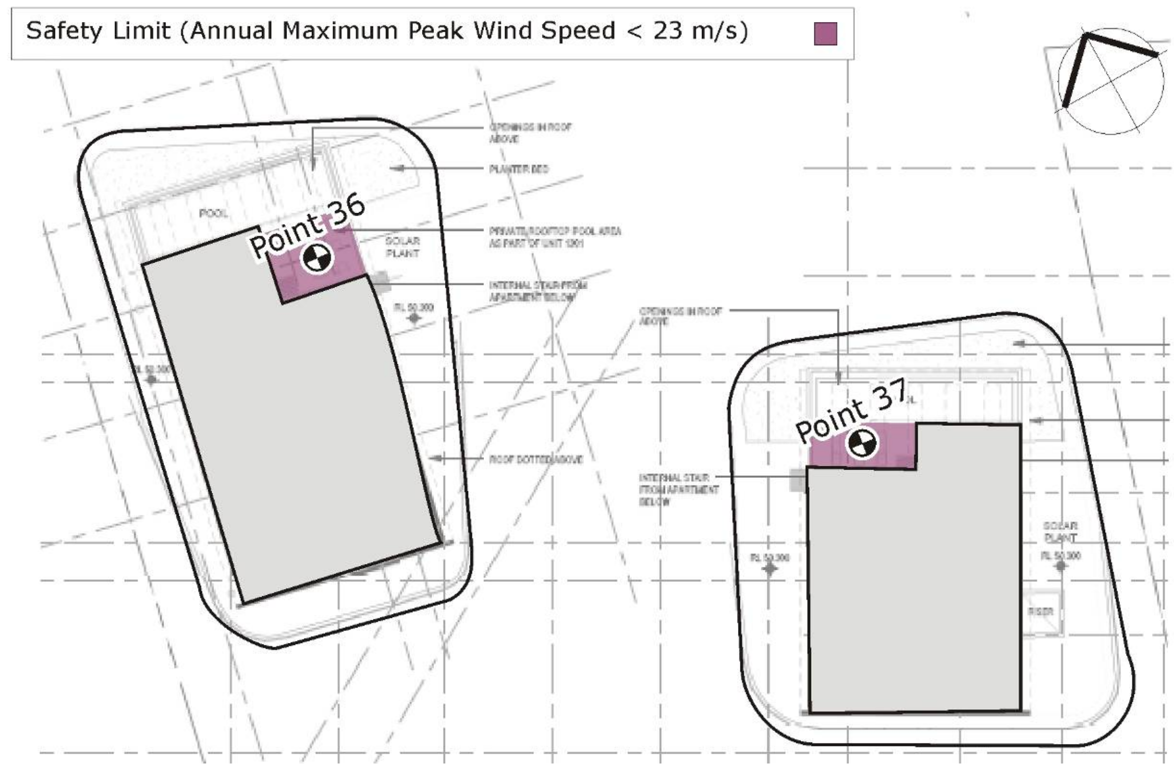


Figure 6f: Study Point Locations & Wind Comfort Criterion Zones Roof Level

Figure 6g: Study Point Locations for the Comparison of the Existing and Future Wind Environment Conditions

5.0 Results of the Study

A detailed study of wind activity around and within the development was carried out. A total of 37 study locations were chosen for detailed analysis as shown in Figures 6a to 6f. These include 16 ground level test point locations within the proposed development, 3 test point locations on the lower level apartment balconies, 14 test point locations on the terraces and roof decks on Level 4 and 5, and 4 test point locations on them higher level balconies and rooftop terraces. An additional 4 study points were used to measure the existing wind conditions for neighbouring areas to the site. These 4 locations were retested with the inclusion of the proposed development to allow for a comparison of the existing and future wind conditions around the site.

The development was initially tested without the effect of any forms of wind ameliorating devices such as screens, balustrades, trees etc that are not indicated on the architectural drawings. For areas not achieving the appropriate wind conditions retests were conducted with some form of treatment.

Plots of results of the local directional wind speeds for the various test locations, as derived from the wind tunnel tests, are presented in the attached Appendix A. The results are based on the weekly maximum peak wind speed criteria and the annual maximum peak wind speed criteria, as outlined in Section 4.5 of this report.

5.1 Ground Level Areas

The Study Points

Points 1 to 16 are used to monitor the Ground Level wind conditions of the site. The locations of these points are shown in Figure 6a.

Applicable Criteria

All ground level study points are used to monitor the wind conditions of the various pedestrian access areas. It is expected that these area will be used primarily as pedestrian thoroughfares. Hence the appropriate wind comfort criterion to be satisfied for these ground level study points is the comfortable walking criterion of 7.5m/s for the weekly GEM wind speeds.

The appropriate wind comfort criteria for all ground level areas are also indicated in Figure 6a. Note that the safety limit for annual maximum peak wind speeds should also be satisfied for all study points.

Results and Recommendations

The results of the initial tests indicate that wind conditions at all ground level areas will satisfy their applicable wind comfort criteria, except for Point 8 which exceeded the comfortable walking criterion for the weekly GEM wind speeds and the safety limit for annual maximum peak wind speeds. This is caused by the adverse funnelling effect of southerly winds through this section of the development site. However, it is expected that the existing the tall trees, as shown in Figure 7a to the south of Point 8, will provide sufficient shielding from southerly winds to enable wind conditions at Point 8 to satisfy the relevant criteria. Hence the existing trees along the Cross Street frontage of the site should be retained in the final design.

With this treatment included into the final design of the proposed development, wind conditions at all outdoor ground level areas of the site will be acceptable for their intended uses.

5.2 Level 4 Communal Terraces and Pool Deck Area

The Study Points

Points 23 to 26 are used to examine the wind conditions on the Level 4 pool deck area and the adjoining bar terrace area where outdoor seating is proposed. Points 20 to 22 are used to examine the wind conditions on the remaining trafficable communal terrace areas of Level 4. The locations of these points are shown in Figure 6c.

Applicable Criteria

Points 24 to 26 represent wind conditions at the pool deck area and the outdoor terrace seating area for the proposed bar on Level 4. These study points represent outdoor areas of the development where the Davenport (1972) comfortable walking criterion of 7.5m/s for the weekly GEM wind speeds is most appropriate. The wind conditions at Point 23 satisfy the Davenport (1972) short exposure criterion of 5.5m/s for the weekly GEM wind speeds as it represents an outdoor seating area.

The appropriate wind comfort criteria for all of these areas are also indicated in Figure 6c. Note that the safety limit for annual maximum peak wind speeds should also be satisfied for all study points.

Results and Recommendations

The initial test results for Points 20 to 23 indicated that only the wind conditions at Point 22 will exceed the relevant comfort criteria. A retest was undertaken with an impermeable 1.2m high balustrade around the terrace perimeter, however this was found to have a negligible effect on the measured wind conditions. Another retest was performed, this time with a 1.2m high impermeable balustrade around only the trafficable area of the terrace as indicated in Figure 7b. With this balustrade, wind conditions at Point 23 were significantly improved and satisfy the recommended wind comfort criteria. Hence it is recommended to include the balustrade indicated in Figure 7b into the final design of the proposed development.

The initial test results for the wind conditions at the Level 4 pool deck area and terrace area (represented by Points 23 to 26) indicate that the recommended criteria will be exceeded. Retests of these study points were undertaken with the addition of a 2m high impermeable balustrade around the pool area. With this treatment in place, the wind conditions at all of these study point locations were well within the limits of the recommended criteria. Hence it is expected that a

1.2m high impermeable balustrade around the pool area will provide sufficient mitigation, and still enable wind conditions in this area to satisfy the comfortable walking criteria. This recommended treatment is shown in Figure 7b.

5.3 Private Balconies and Terraces

The Study Points

Private balconies and terraces are proposed for most levels of the development. The location of the various study points used to measure the wind conditions for these areas is summarised as follows:

- Points 17 to 19 monitor wind conditions on the lower level balconies on the northern end of the site.
- Points 27 to 29 monitor wind conditions on the podium rooftop area on Level 5, between the two main towers of the development.
- Points 30 and 31 monitor wind conditions on the Level 5 terrace at the north-western corner of the site.
- Points 32 and 33 monitor wind conditions on the Level 5 balconies at the north-eastern corner of the site.
- Point 34 monitors wind conditions to the balconies at the north-western corner of the western tower.
- Point 35 monitors wind conditions to the balconies at the north-eastern corner of the eastern tower.
- Point 36 monitors wind conditions at the roof level balcony on the western tower.
- Point 37 monitors wind conditions at the roof level balcony on the eastern tower.

The locations of all of these study points are also shown in Figures 6b, 6d, 6e and 6f.

Applicable Criteria

Wind conditions on private terraces and balconies are expected to satisfy the safety limit of 23 m/s for annual maximum peak wind speeds. The appropriate wind comfort criteria for the various private balcony and terrace areas of the proposed development are also indicated in Figures 6b, 6d, 6e and 6f.

Results and Recommendations

The results of the initial tests indicate that wind conditions for most of the private balcony and terrace areas of the proposed development will be acceptable for the intended uses without the need for any ameliorative treatments. The following study points were retested with various forms of ameliorative treatments:

- Points 27 to 29, located on the Level 5 podium rooftop between the two main towers of the development, were retested with 2m high impermeable screens on the perimeter of that area (as indicated in Figure 7c) to ameliorate the wind funnelling effect between the two main towers.

- Point 31, which monitors wind conditions on the north-western Level 5 terrace area, was retested with the addition of a 1.2m high impermeable balustrade around the perimeter of the terrace area (as indicated in Figure 7c) to ameliorate the adverse westerly winds.

- Points 32 and 33, which monitor wind conditions on the Level 5 balconies at the north-eastern corner of the site, were retested with 2m high impermeable screens around the floor slab perimeter to ameliorate the adverse winds affecting these areas.

- Point 35, which monitors wind conditions on the balconies at the north-eastern corner of the eastern tower, was retested with the addition of an impermeable 1.2m high impermeable balustrade (as indicated in Figure 7d) to ameliorate the adverse north-easterly and southerly winds affecting those balconies.

The above treatments were generally found to be effective. However, the treatment test results for Points 32 and 33 indicate that the 2m high screens are overly effective; hence it is recommended that 1.2m high impermeable balustrades are used around the balconies represented by these study points as indicated in Figure 7c.

The retest results for Points 27, 28 and 29 indicate that the 2m high impermeable screens will be effective in mitigating the adverse winds affecting this area. As an alternative treatment solution, a combination of some densely foliating trees and 1.2m high impermeable balustrades, as indicated in Figure 7c, is also expected to provide a similar mitigating effect to the screens that were tested in the wind tunnel. Note that for trees to be effective in wind mitigation, they should be of a densely foliating variety, and these trees should be capable of growing to a height of at least 3m. Hence, with the treatments shown in Figure 7c, the wind conditions are expected to satisfy the recommended criteria for this area.

5.4 Comparison with the Existing Wind Conditions around the Site

The Study Points

Points A, B, C and D are used to monitor the wind conditions around the proposed development site. The locations of these points are shown in Figure 6g.

Applicable Criteria

Rather than wind comfort criteria, the results of the existing wind conditions are directly compared to the results of the same study points tested with the inclusion of the proposed development.

Results and Recommendations

The results of the testing indicated that, with the inclusion of the proposed development, the wind conditions at all study points will be generally equivalent to the existing conditions. Note that Point A was tested with the existing trees along the Cross Street frontage of the development site still in place (as indicated in Figure 7a).

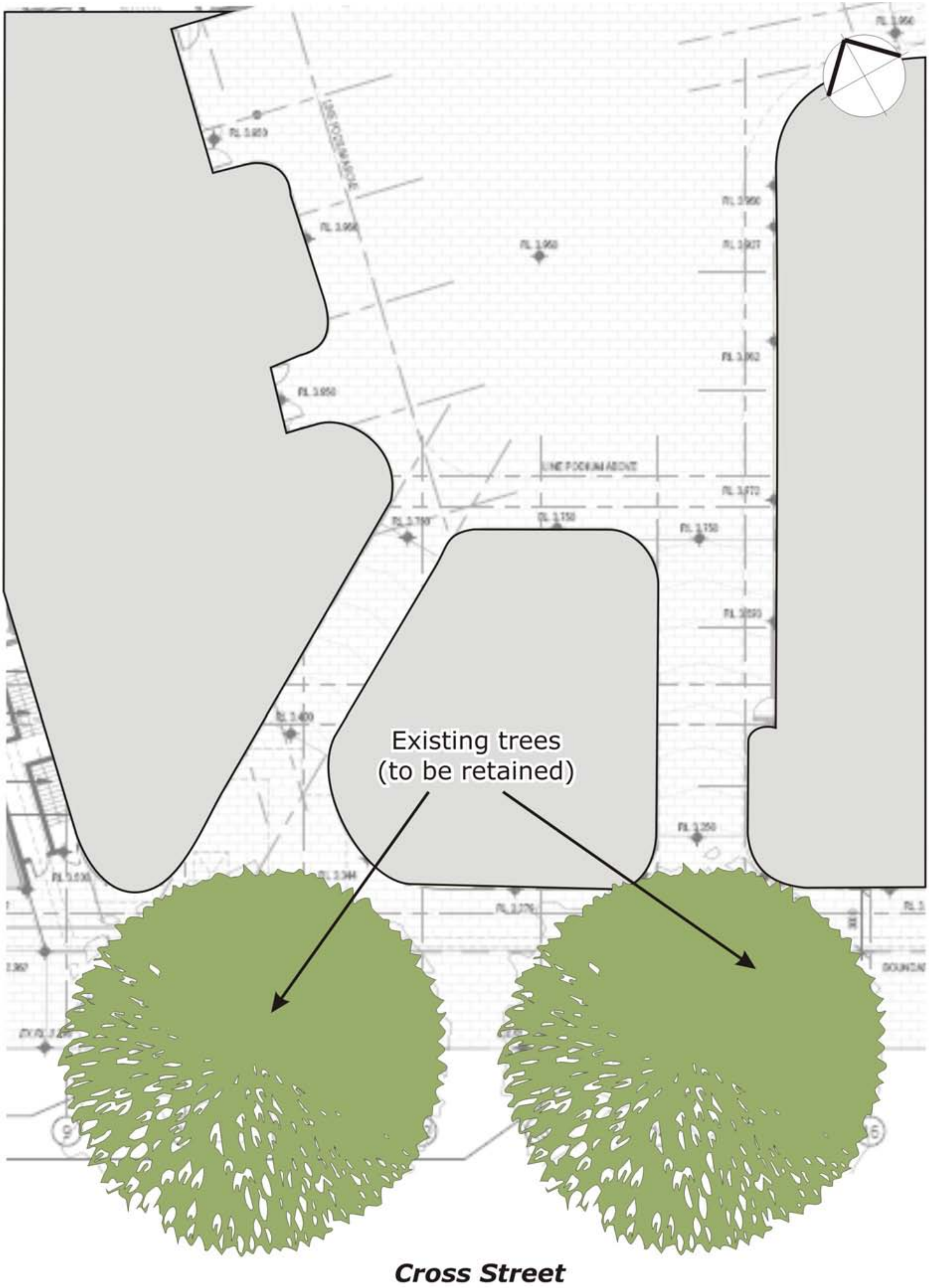


Figure 7a: Recommended Treatments – Ground Level

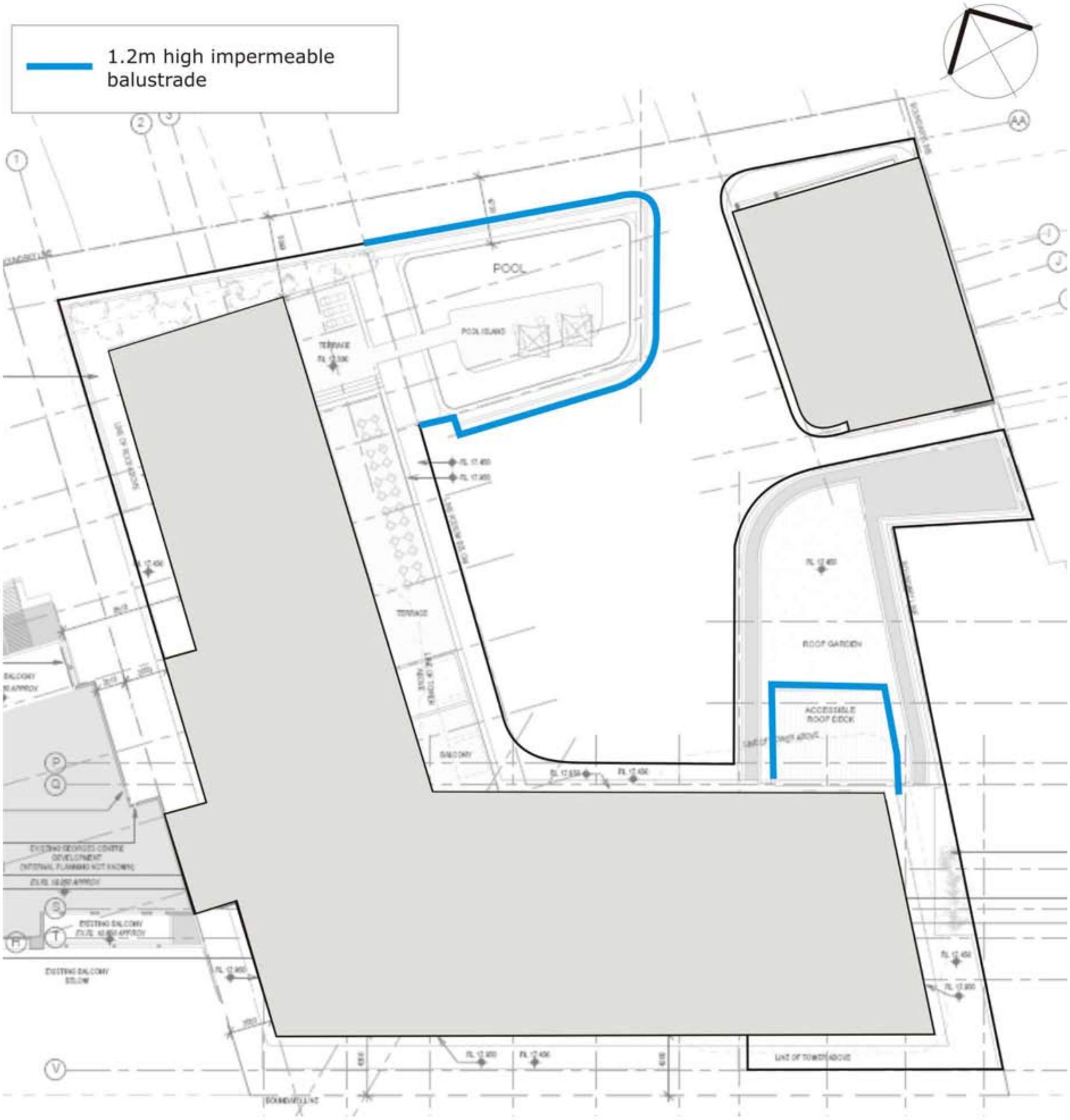


Figure 7b: Recommended Treatments – Level 4

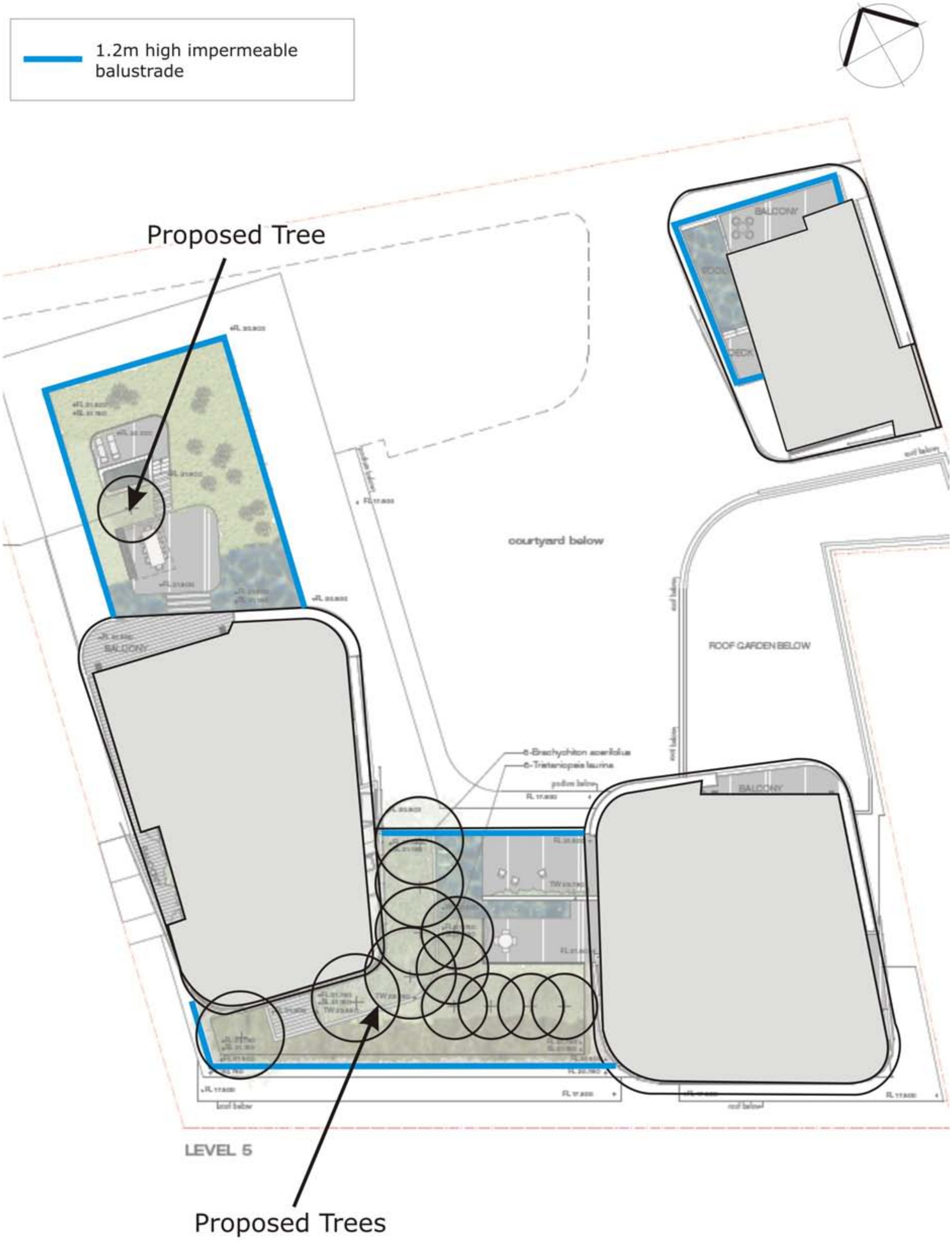


Figure 7c: Recommended Treatments – Level 5

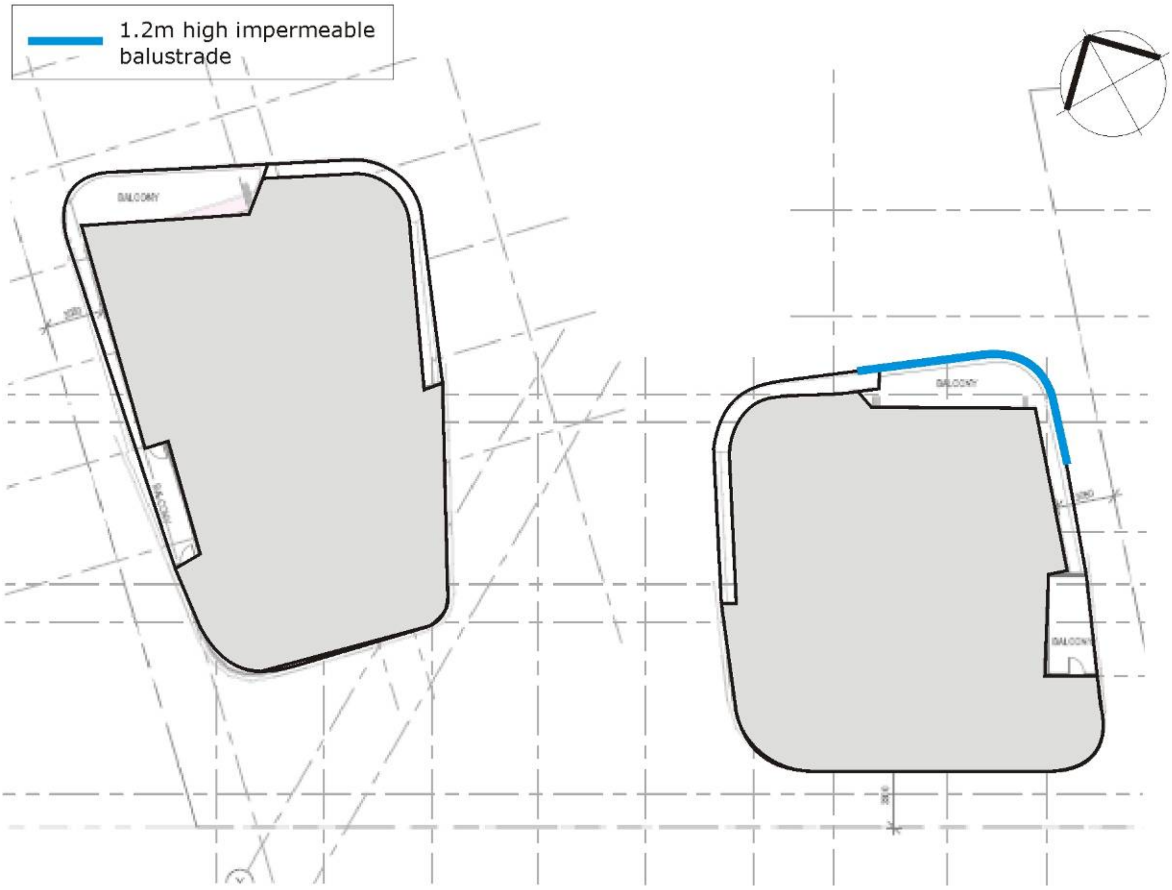


Figure 7d: Recommended Treatments – Typical Tower Levels

6.0 Conclusion

A wind tunnel study has been carried out to investigate the wind environment effects pertaining to the proposed development at 33 Cross Street, Double Bay.

The results of this study indicate that wind conditions at some of the outdoor areas of the proposed development will exceed the relevant criteria. The following treatments are recommended for the development:

- Retain the existing trees along the Cross Street frontage of the site.
- 1.2m high impermeable balustrades around some of the terraces and balconies.
- Densely foliating trees at on Level 5 rooftop areas as defined in architectural drawings.

The above treatments have been modelled and tested in the wind tunnel to verify their effectiveness. With these treatments included into the final design of the development, the wind conditions within and around the proposed development site will be acceptable for their intended uses.

The comparison of the existing and future wind conditions around the site indicates that there will be no adverse wind effects caused by the proposed development.

References

Aynsley, R.M., Melbourne, W., Vickery, B.J., 1977, “Architectural Aerodynamics”, Applied Science Publishers.

Davenport, A.G., 1972, “An approach to human comfort criteria for environmental conditions”, Colloquium on Building Climatology, Stockholm.

Lawson, T.V., 1973, “The wind environment of buildings: a logical approach to the establishment of criteria”, Bristol University, Department of Aeronautical Engineering.

Lawson, T.V., 1975, “The determination of the wind environment of a building complex before construction”, Bristol University, Department of Aeronautical Engineering.

Melbourne, W.H., 1978, "Criteria for Environmental Wind Conditions", Journal of Wind Engineering and Industrial Aerodynamics, vol.3, pp.241-249.

Melbourne, W.H., 1978, "Wind Environment Studies in Australia", Journal of Wind Engineering and Industrial Aerodynamics, vol.3, pp.201-214.

Penwarden, A.D., and Wise A.F.E., 1975, "Wind Environment Around Buildings", Building Research Establishment Report, London.

Ratcliff, M.A. and Peterka, J.A., 1990, “Comparison of Pedestrian Wind Acceptability Criteria", Journal of Wind Engineering and Industrial Aerodynamics, vol.36, pp.791-800.

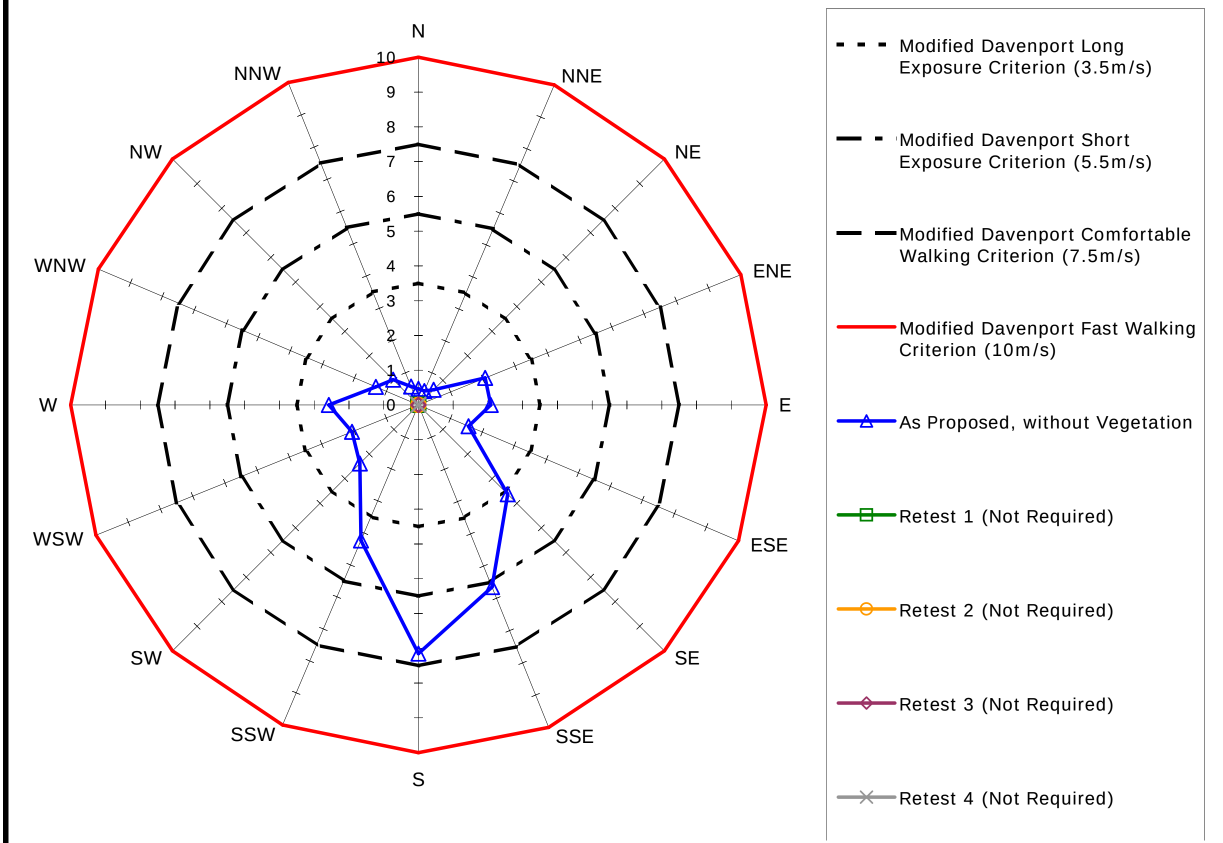
Rofail, A.W., 2007, “Comparison of Wind Environment Criteria against Field Observations”, 12th International Conference of Wind Engineering (Volume 2), Cairns, Australia

Appendix A

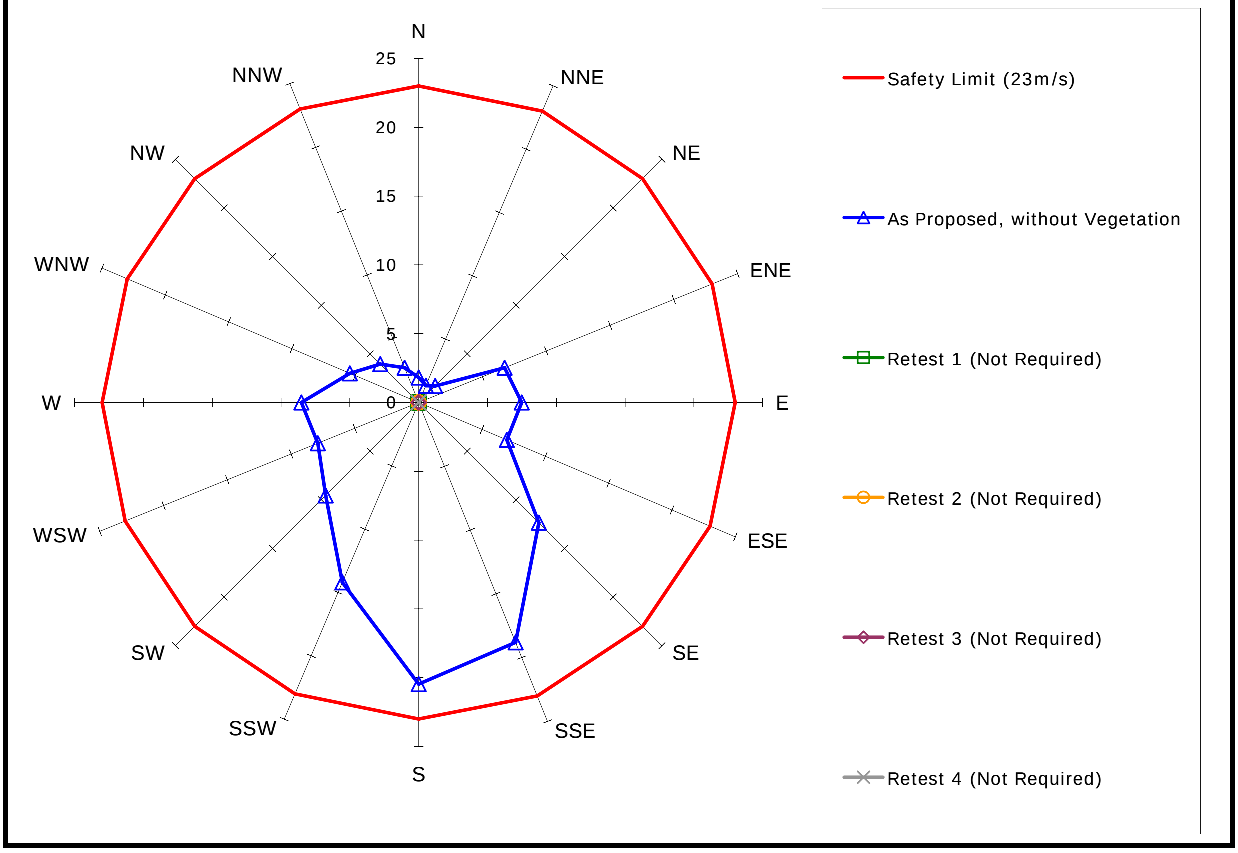
Plots of Wind Tunnel Results

Measured Wind Speeds at Point 01

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

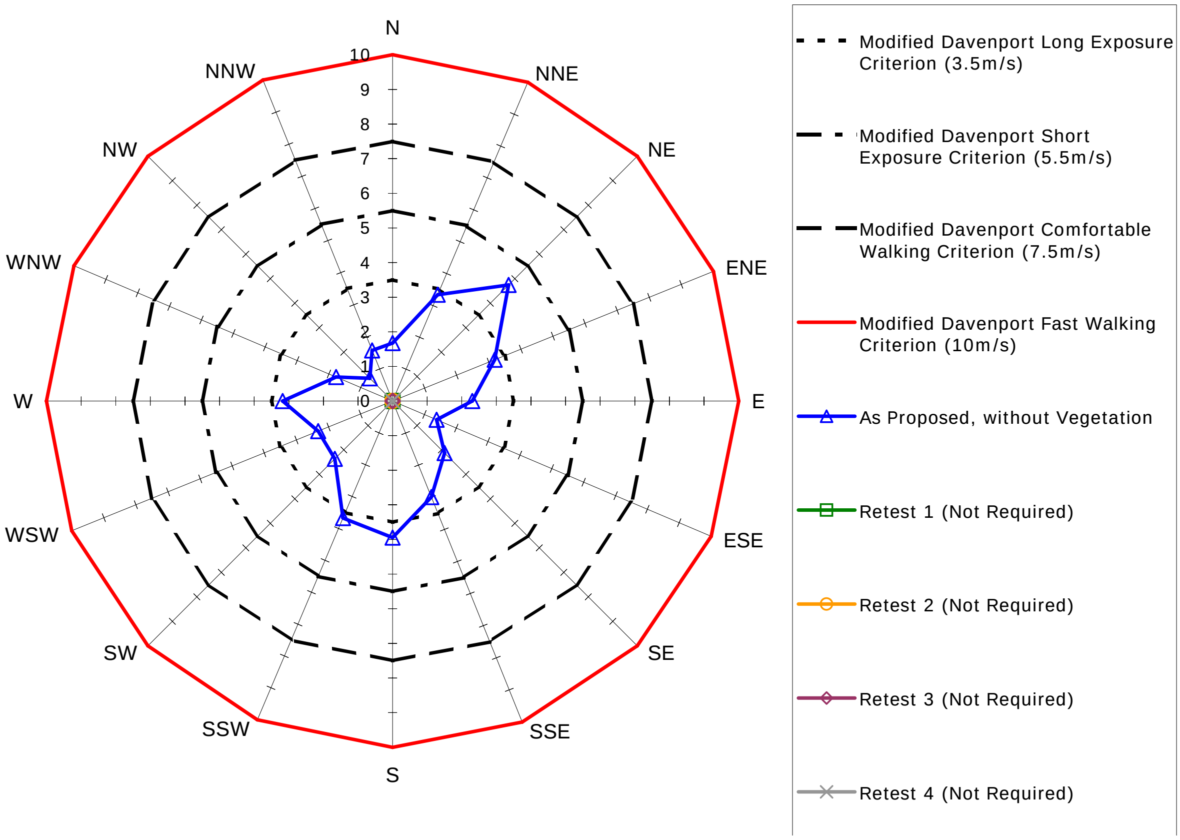


Annual Maximum Gust Wind Speeds (m/s)

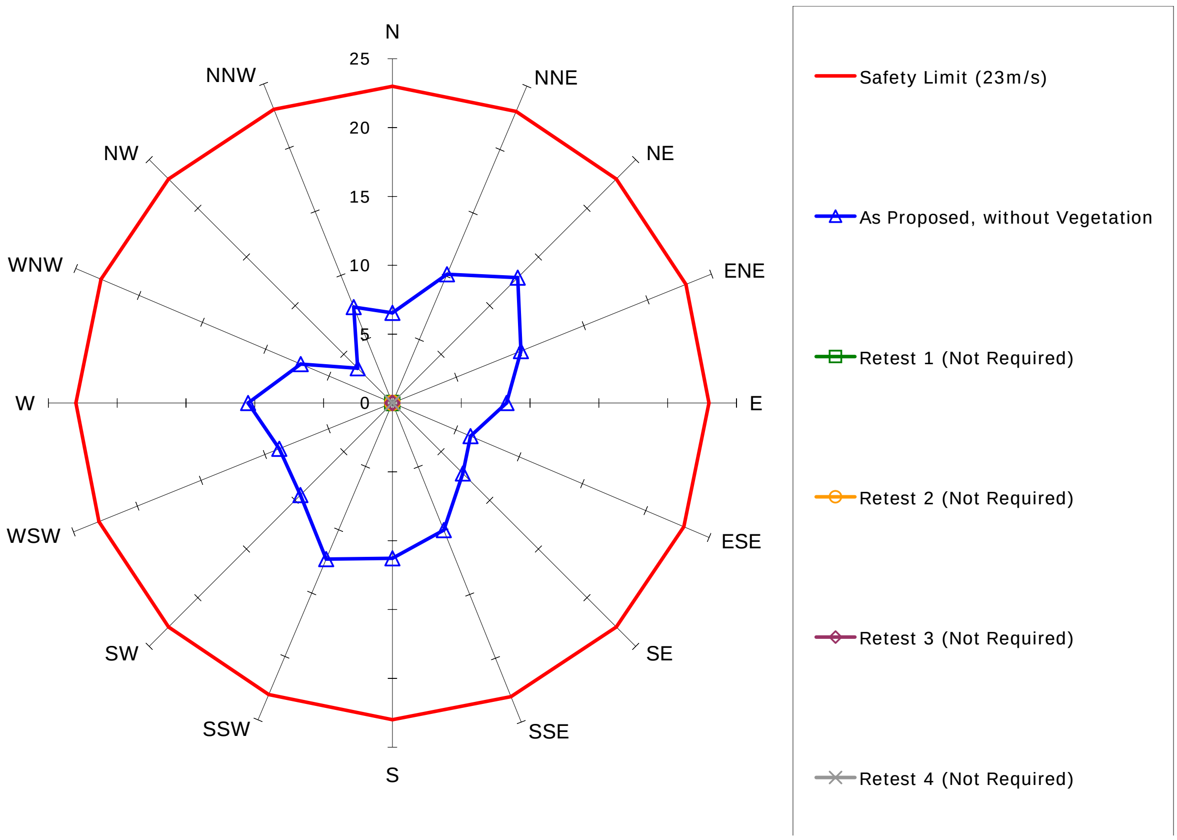


Measured Wind Speeds at Point 02

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

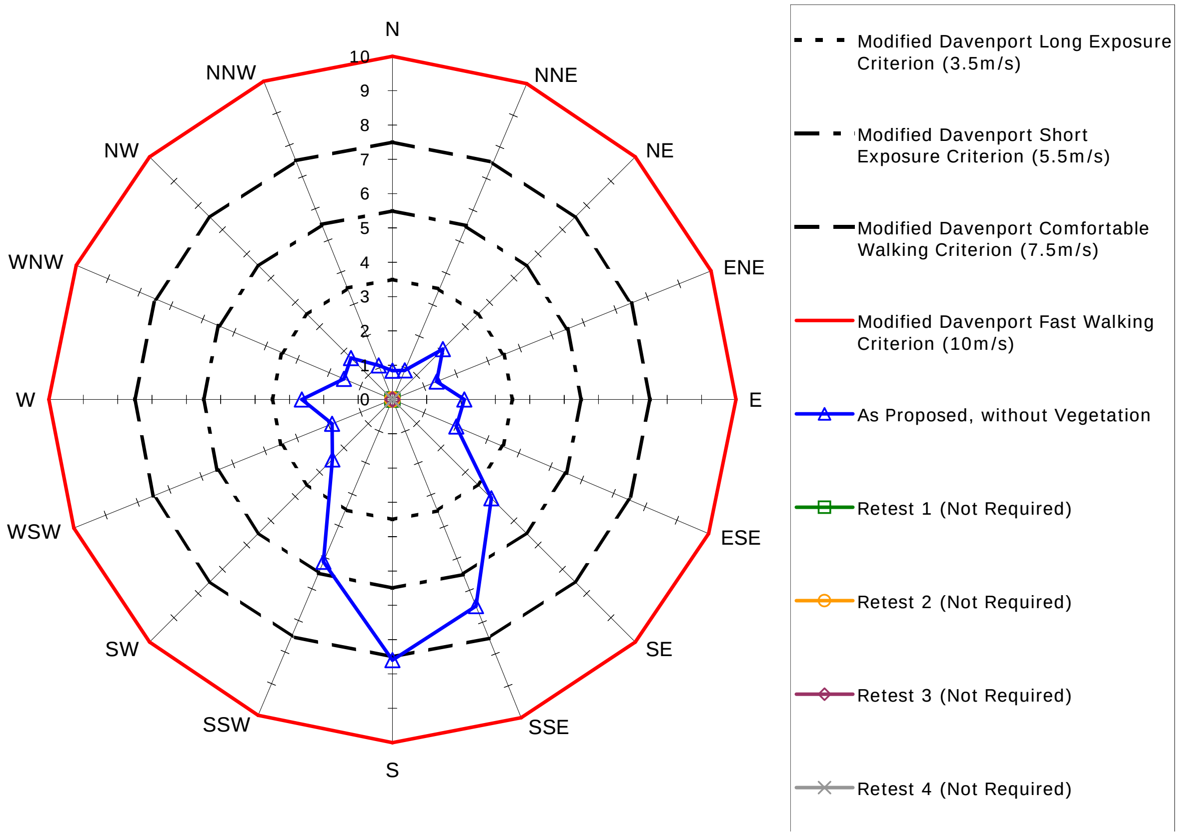


Annual Maximum Gust Wind Speeds (m/s)

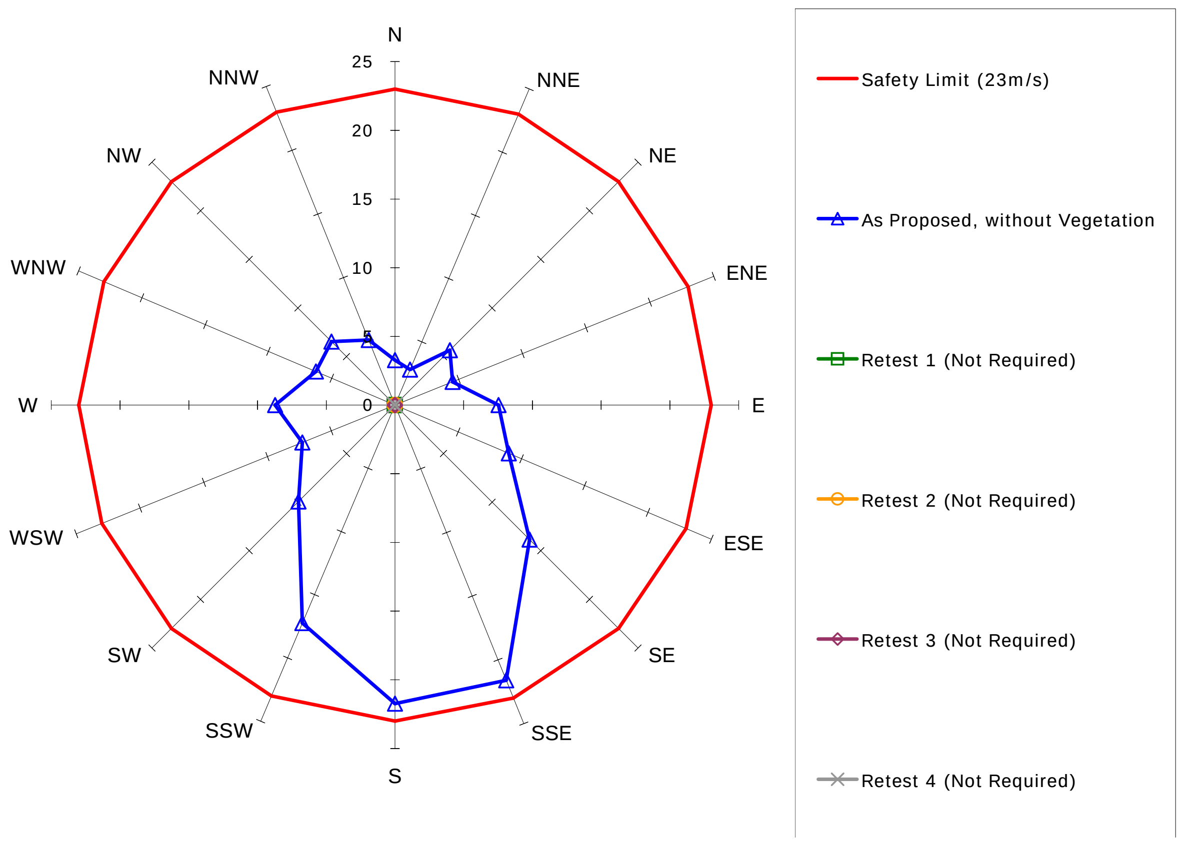


Measured Wind Speeds at Point 03

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

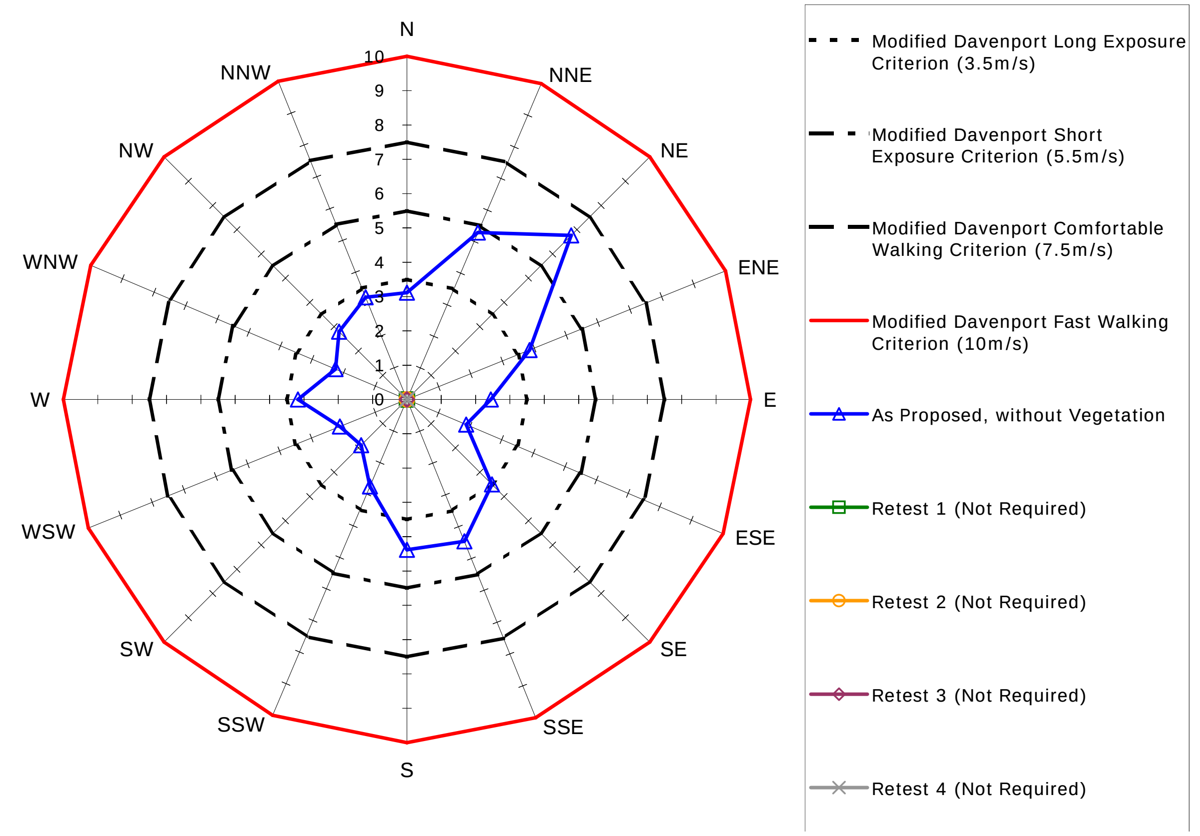


Annual Maximum Gust Wind Speeds (m/s)

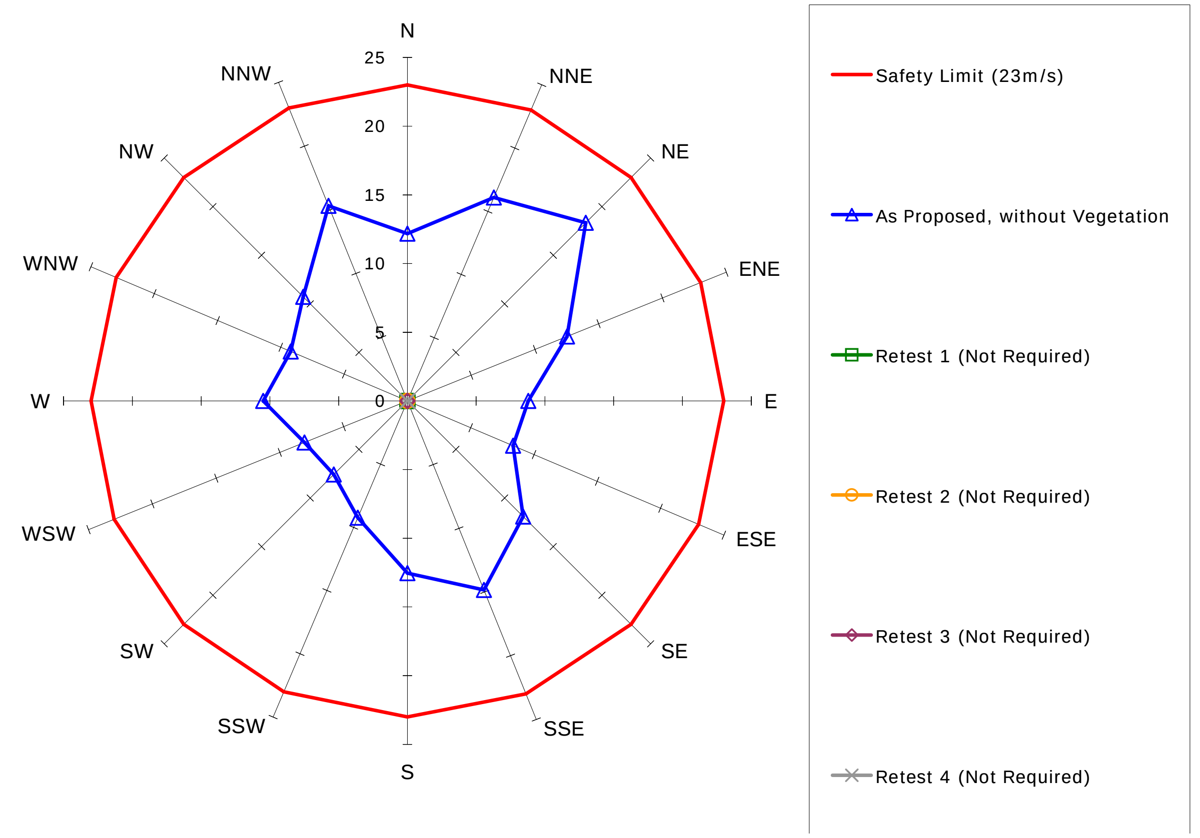


Measured Wind Speeds at Point 04

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

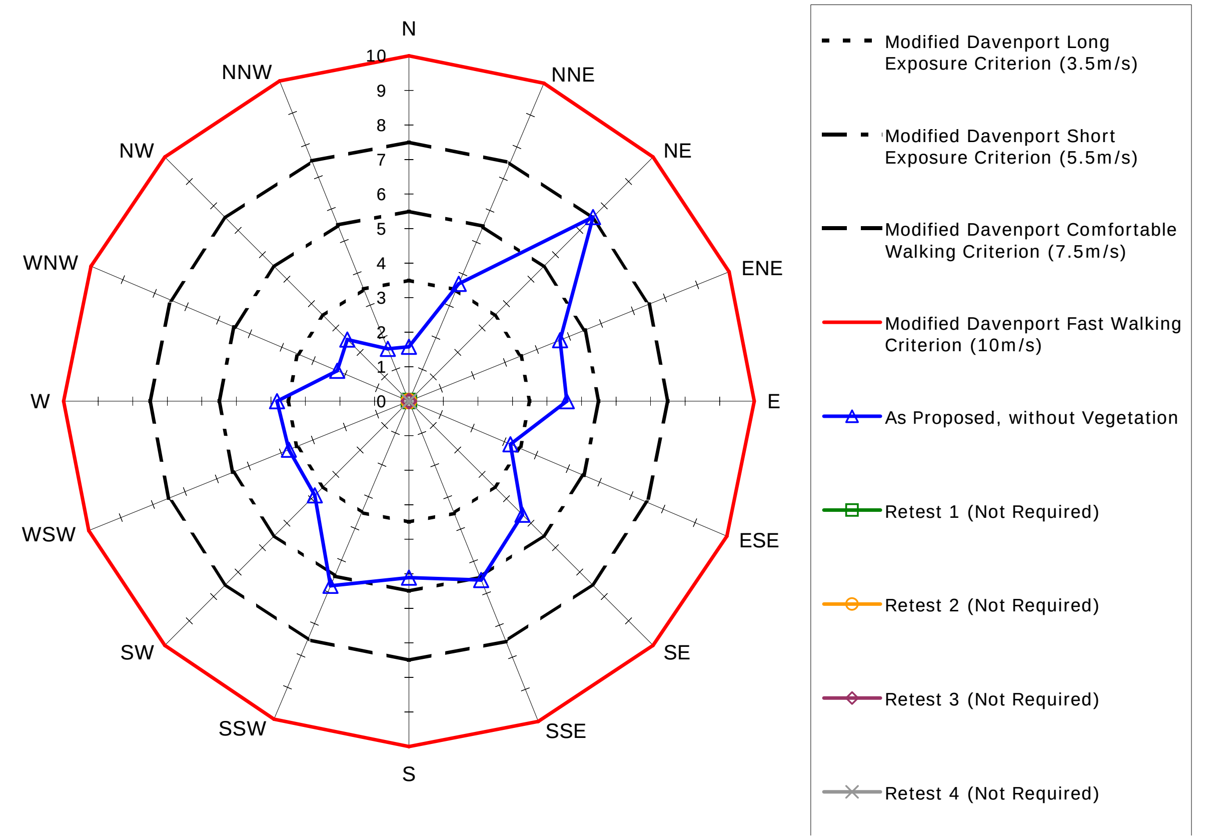


Annual Maximum Gust Wind Speeds (m/s)

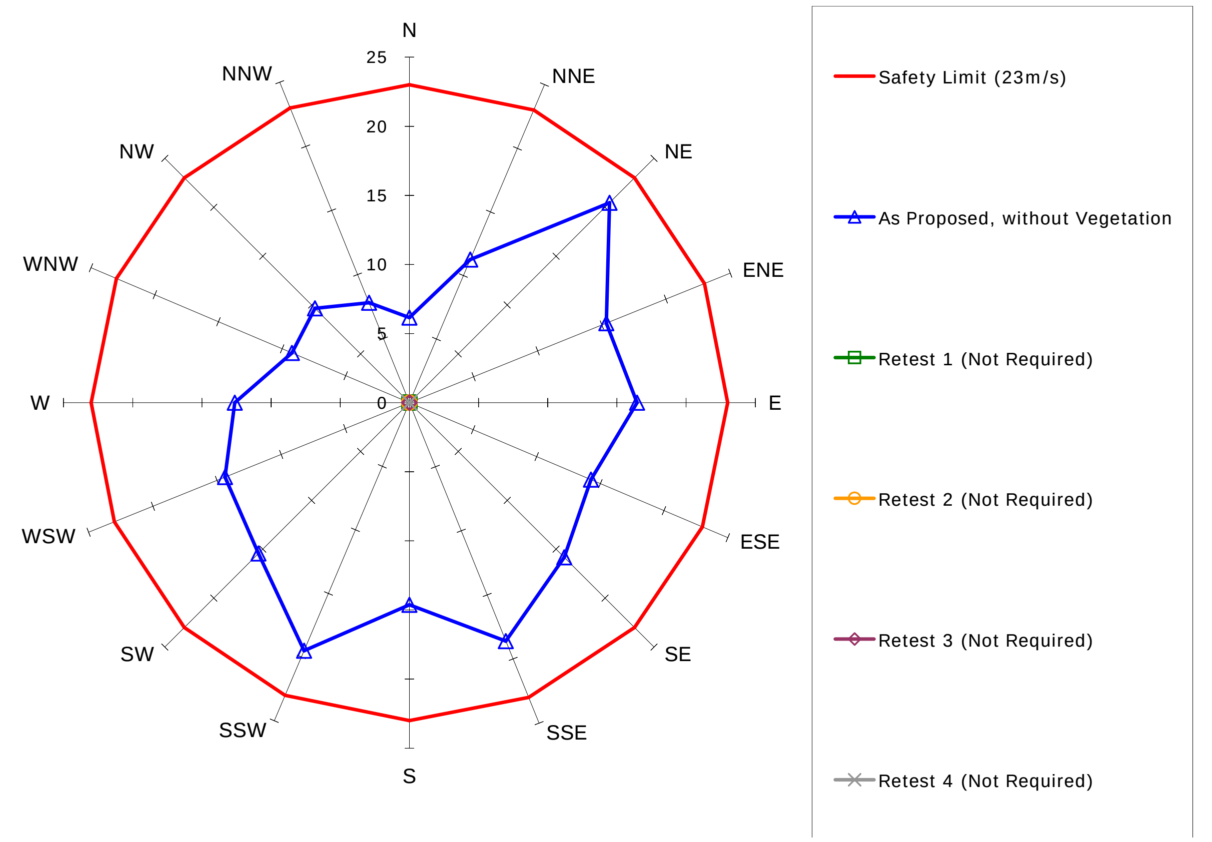


Measured Wind Speeds at Point 05

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

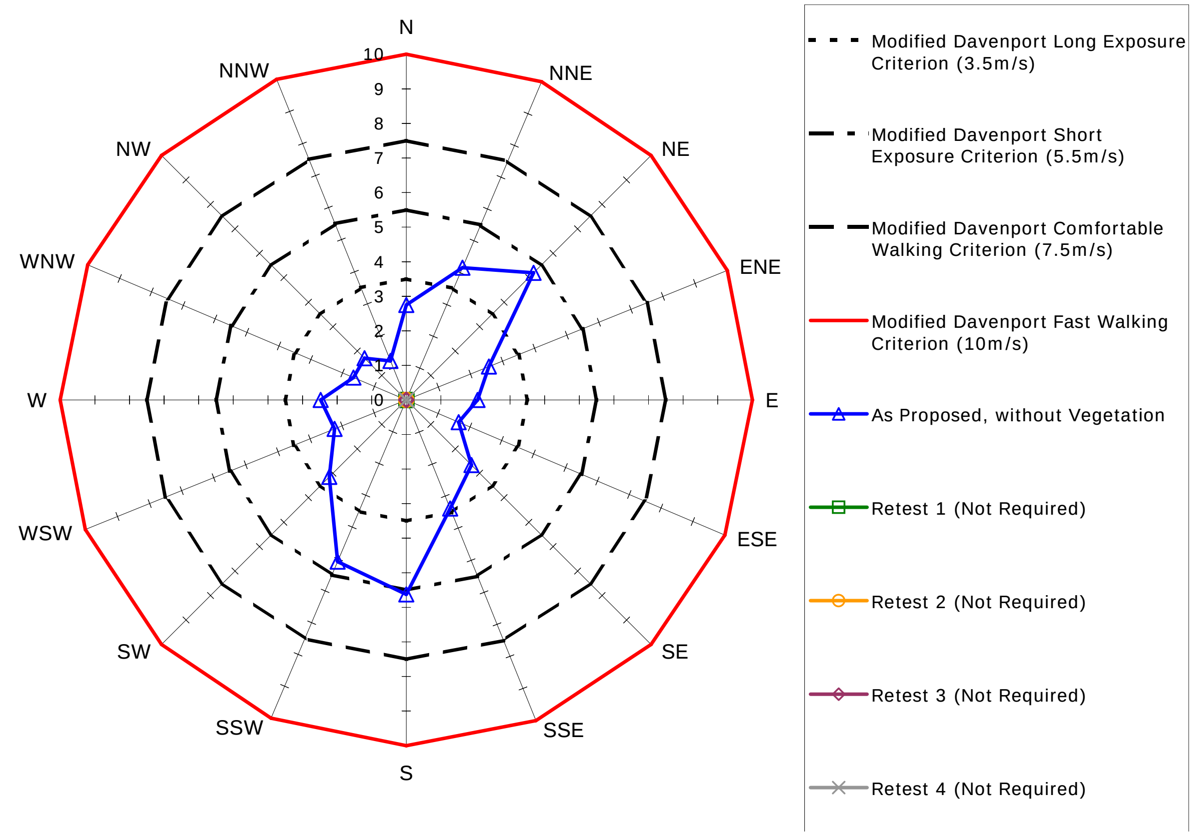


Annual Maximum Gust Wind Speeds (m/s)

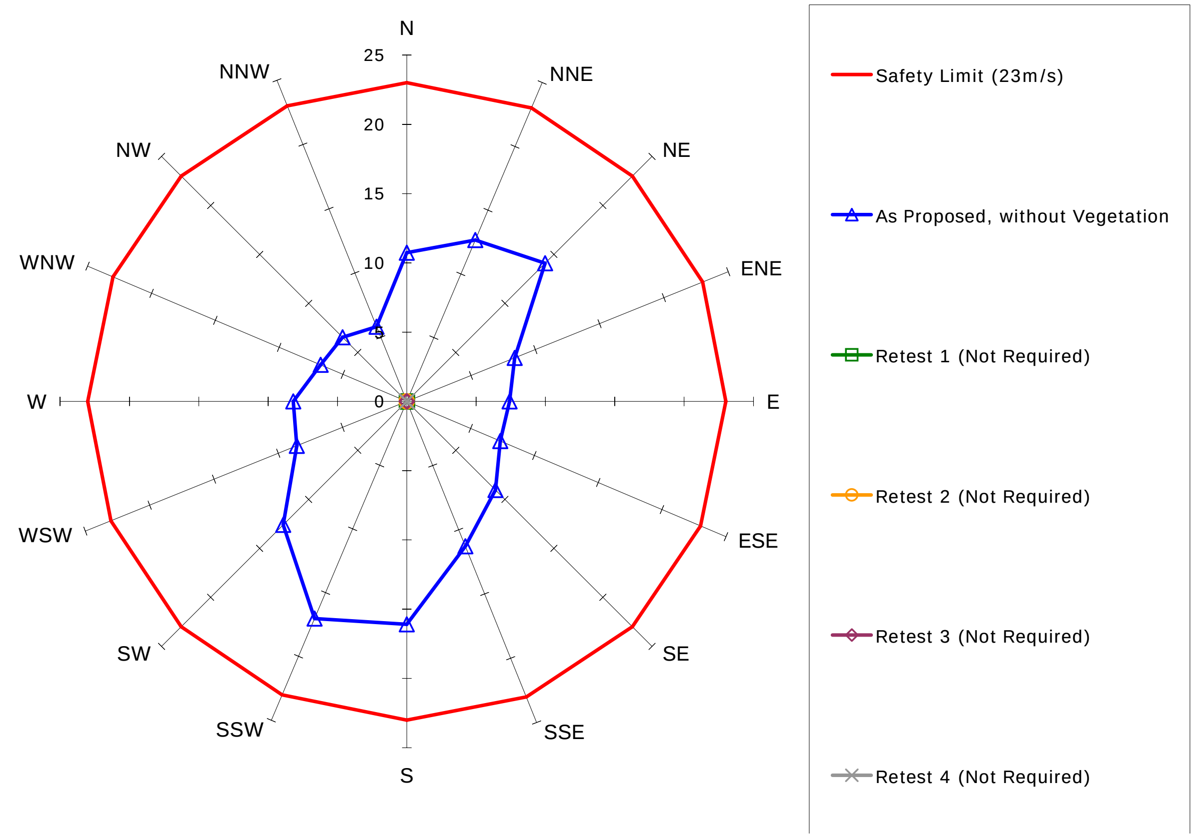


Measured Wind Speeds at Point 06

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

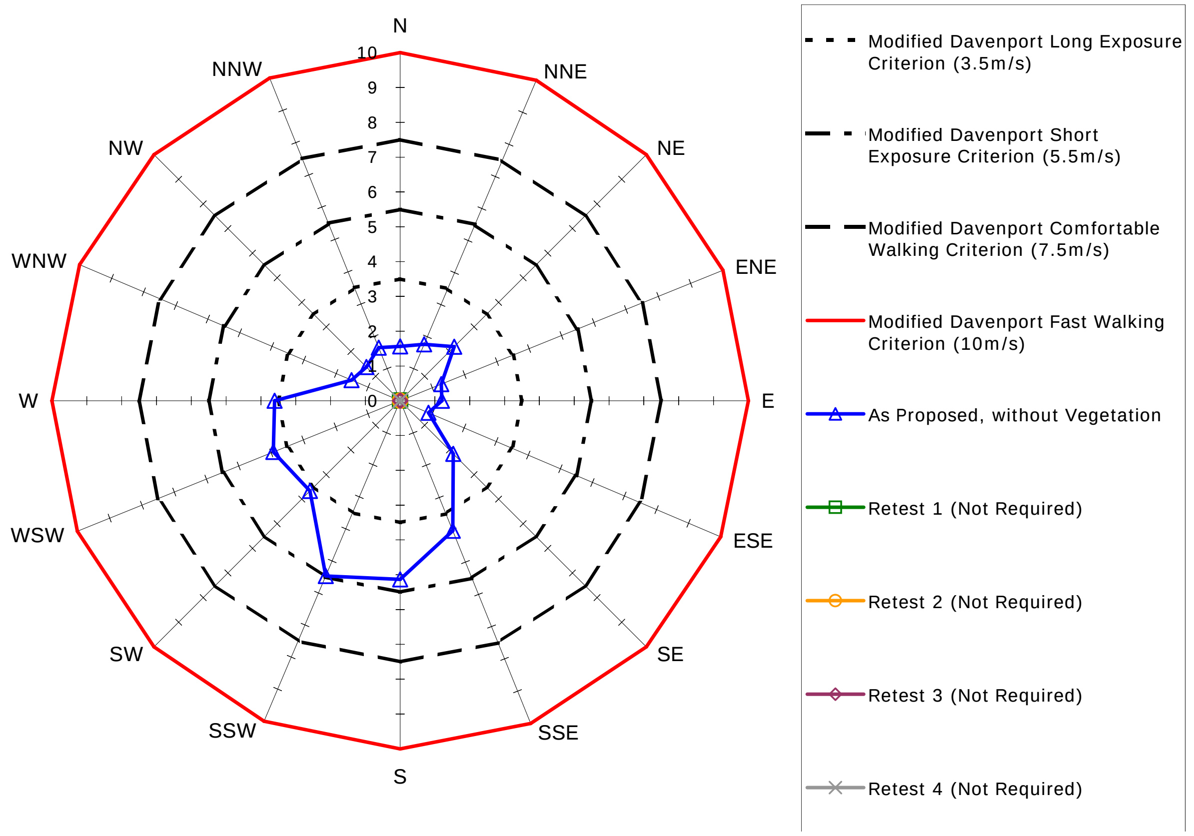


Annual Maximum Gust Wind Speeds (m/s)

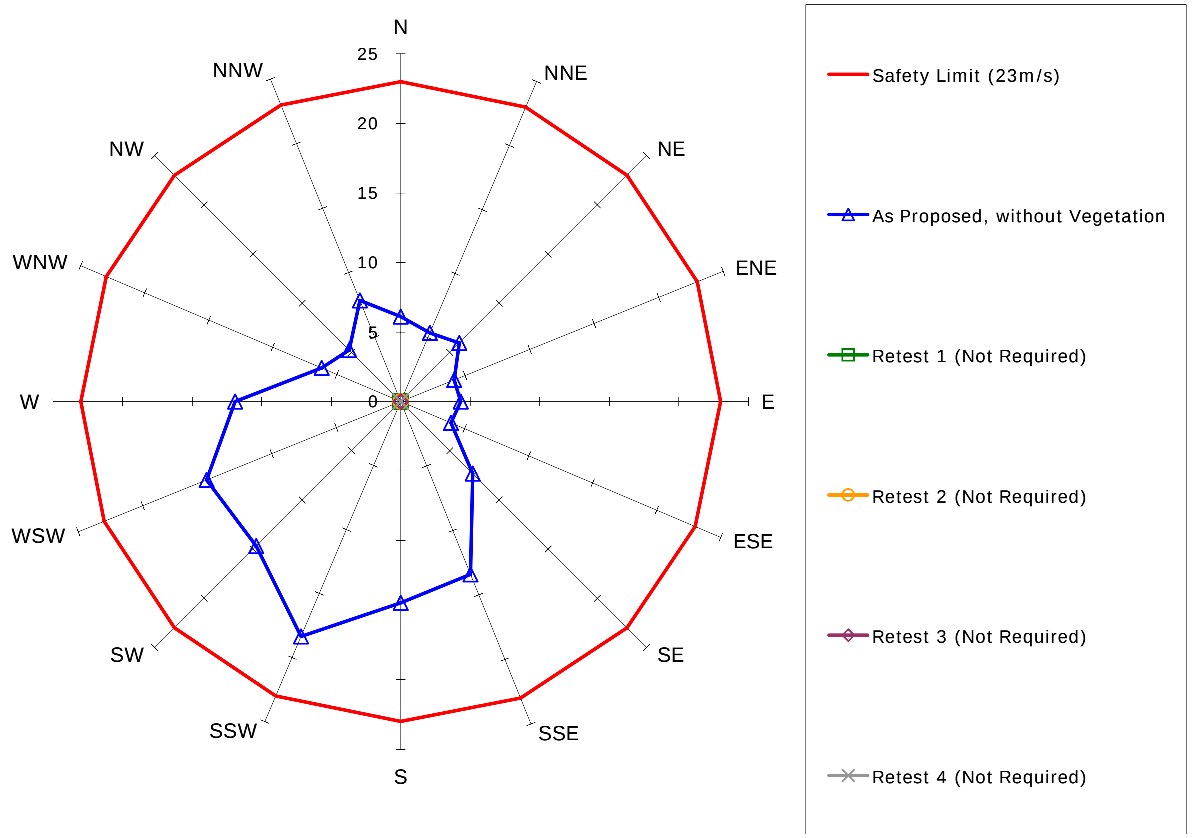


Measured Wind Speeds at Point 07

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

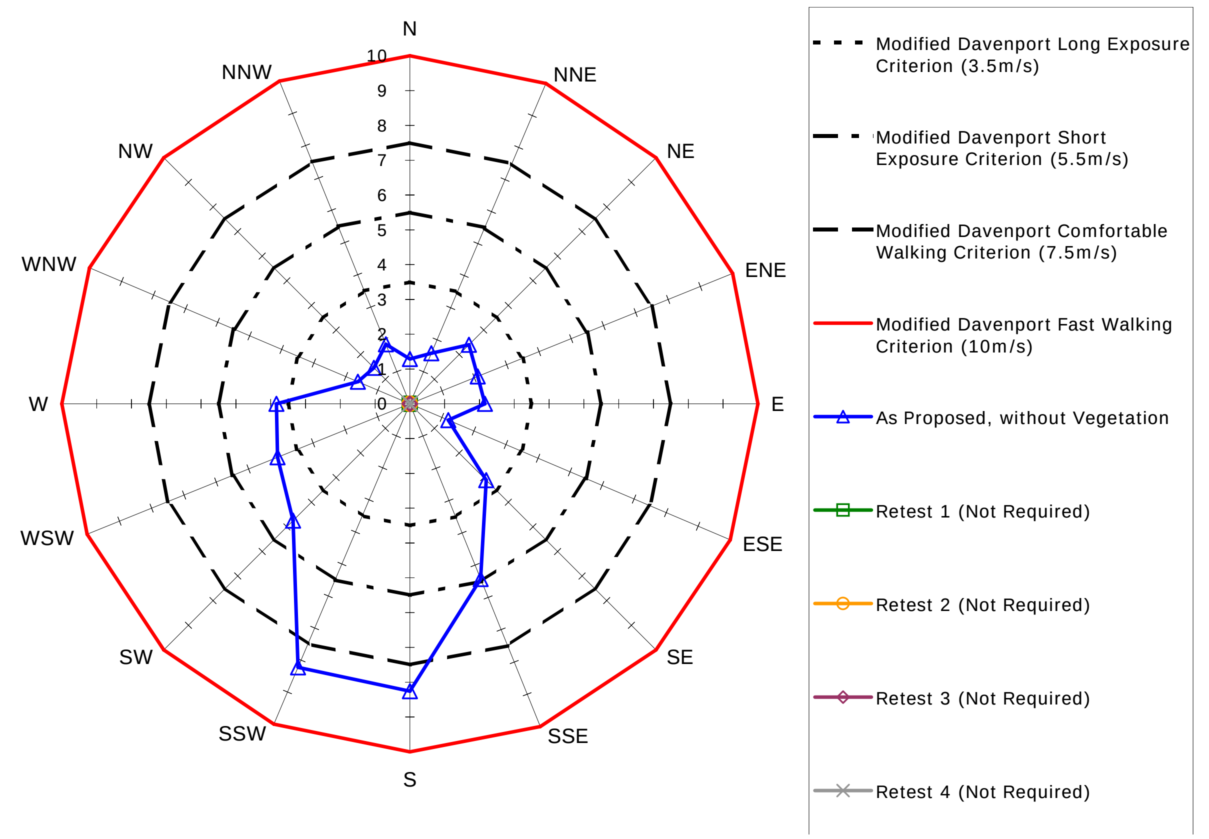


Annual Maximum Gust Wind Speeds (m/s)

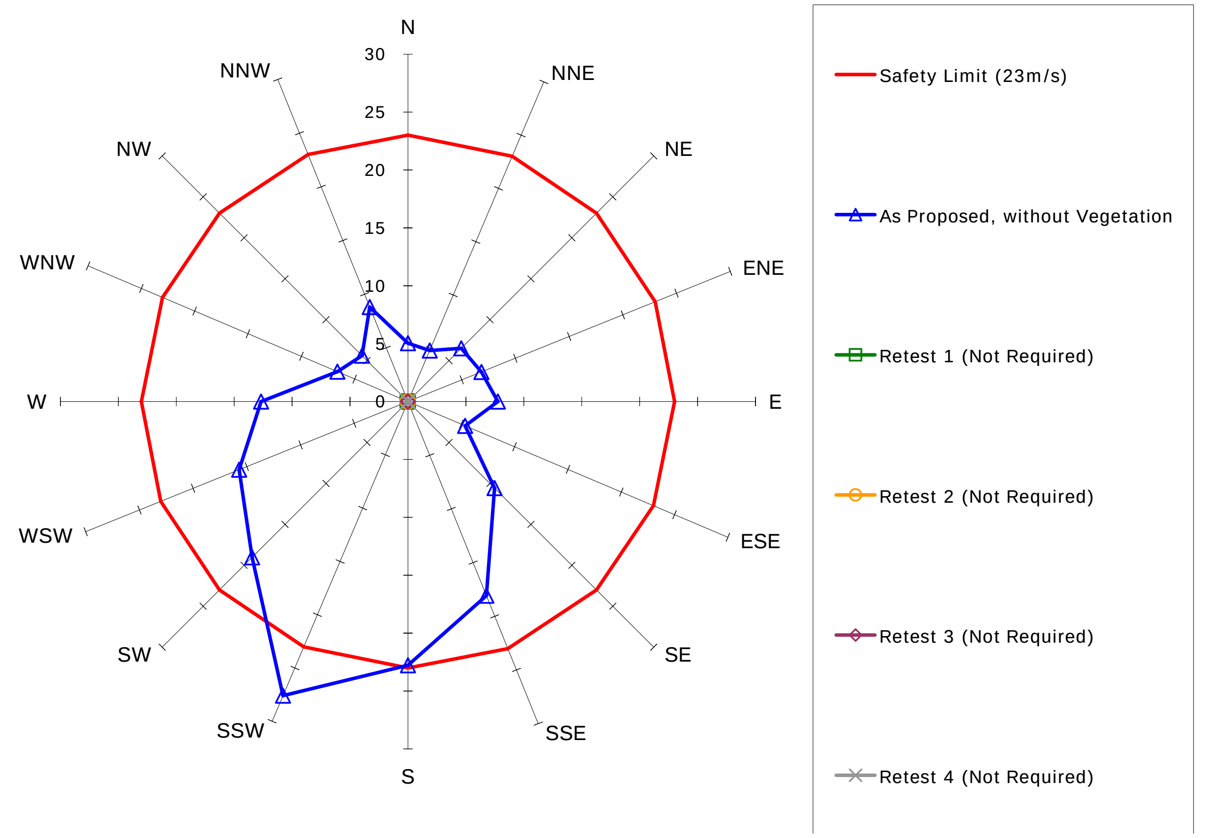


Measured Wind Speeds at Point 08

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

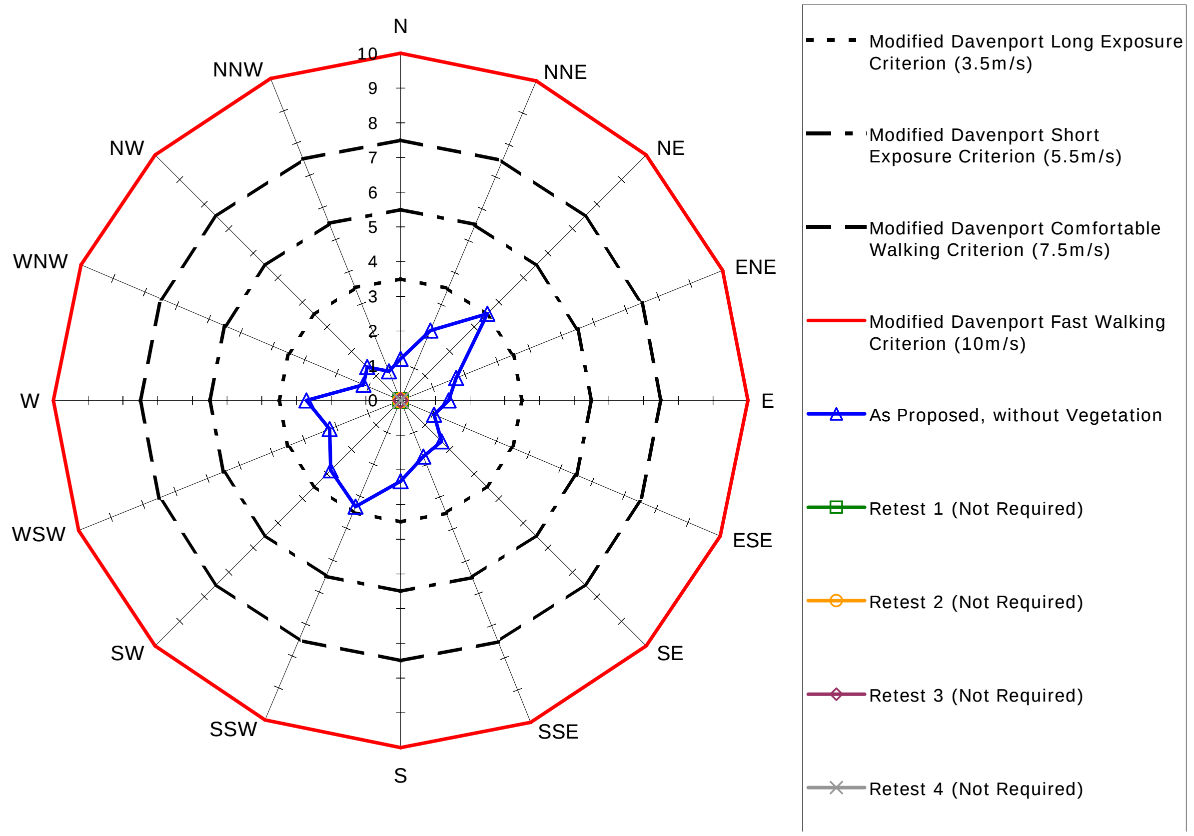


Annual Maximum Gust Wind Speeds (m/s)

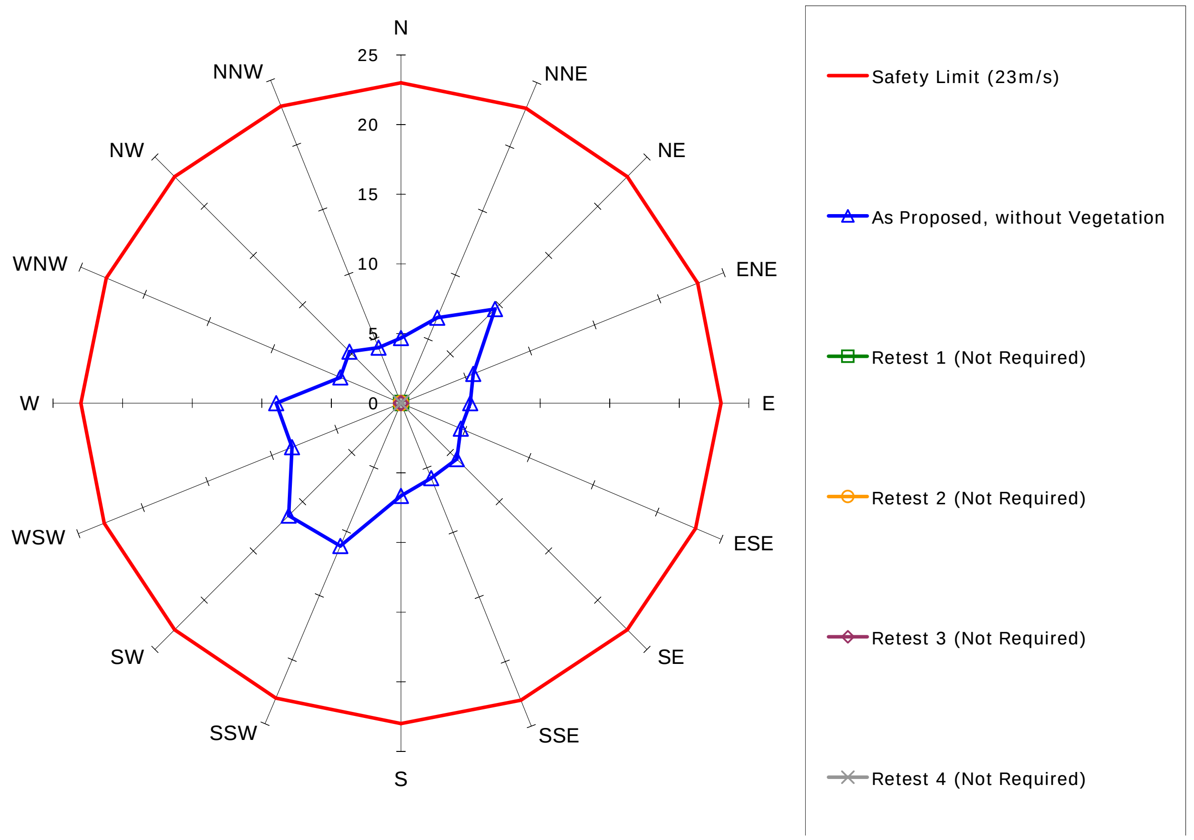


Measured Wind Speeds at Point 09

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

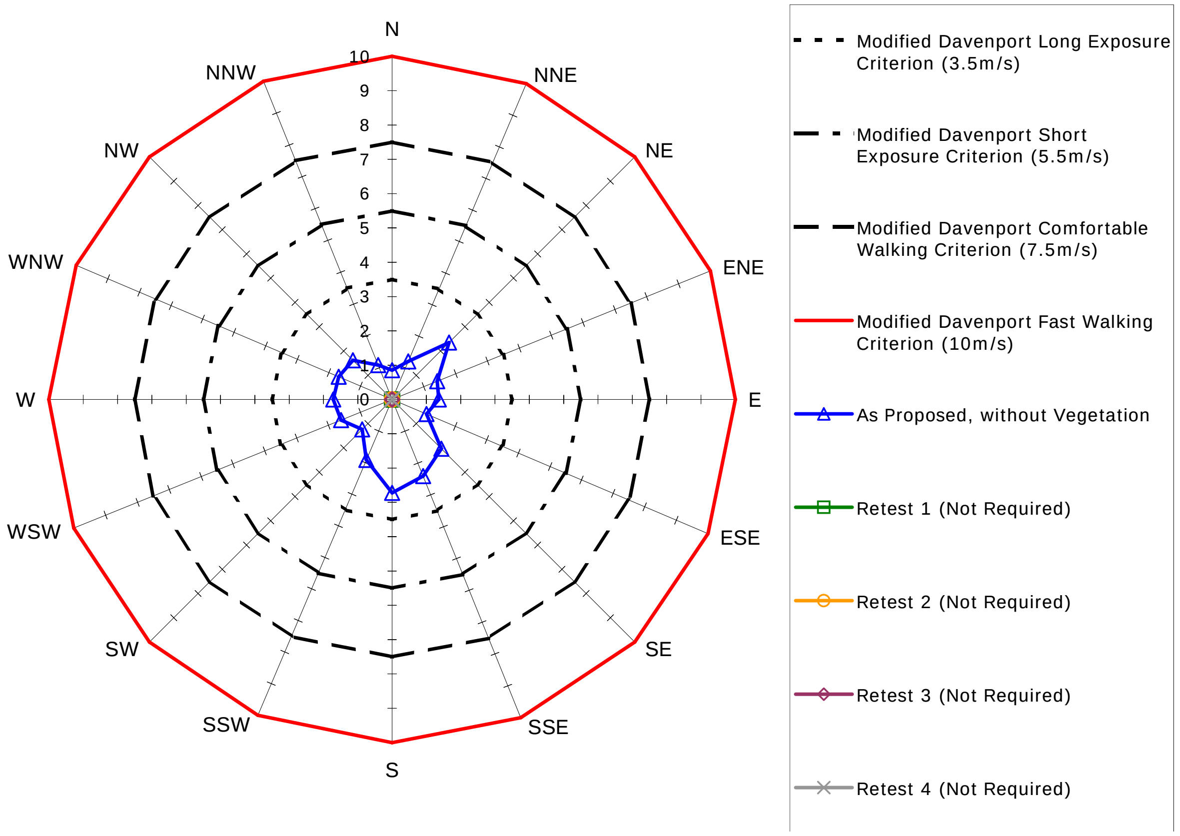


Annual Maximum Gust Wind Speeds (m/s)

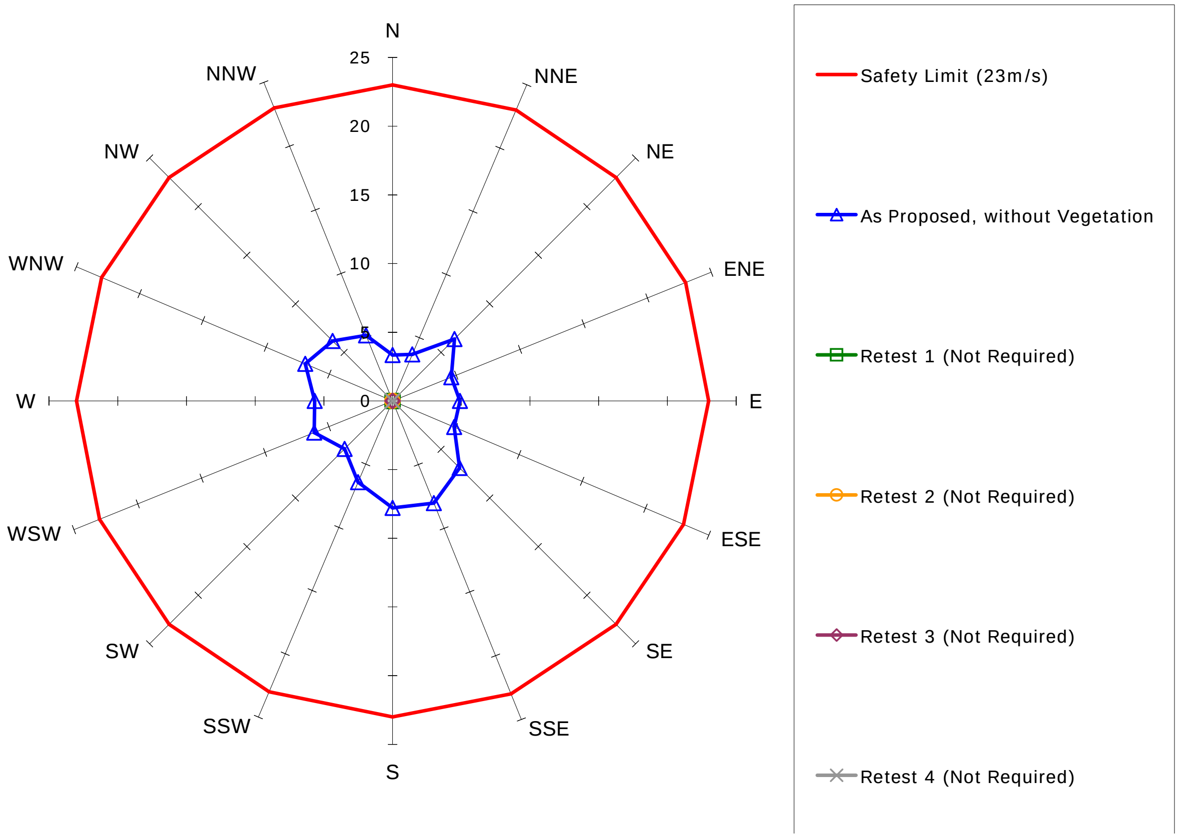


Measured Wind Speeds at Point 10

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

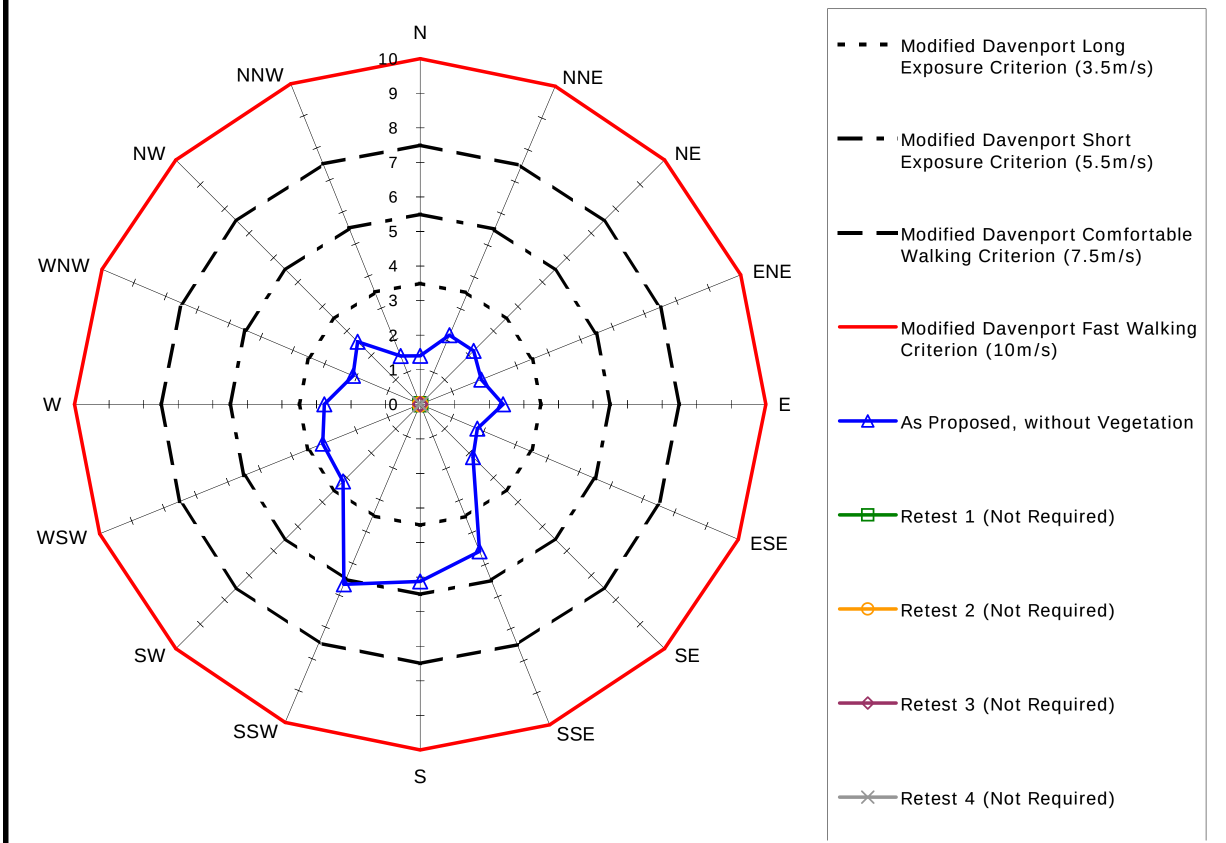


Annual Maximum Gust Wind Speeds (m/s)

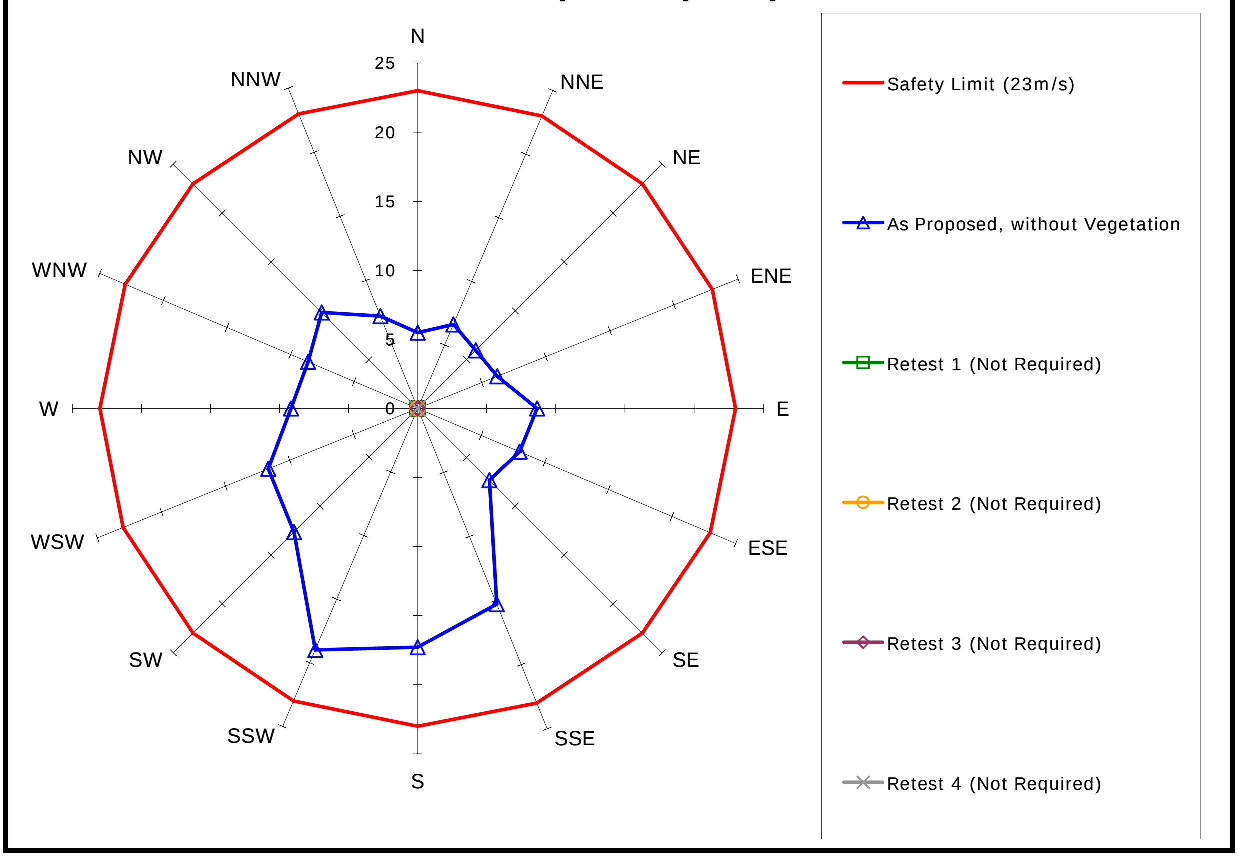


Measured Wind Speeds at Point 11

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

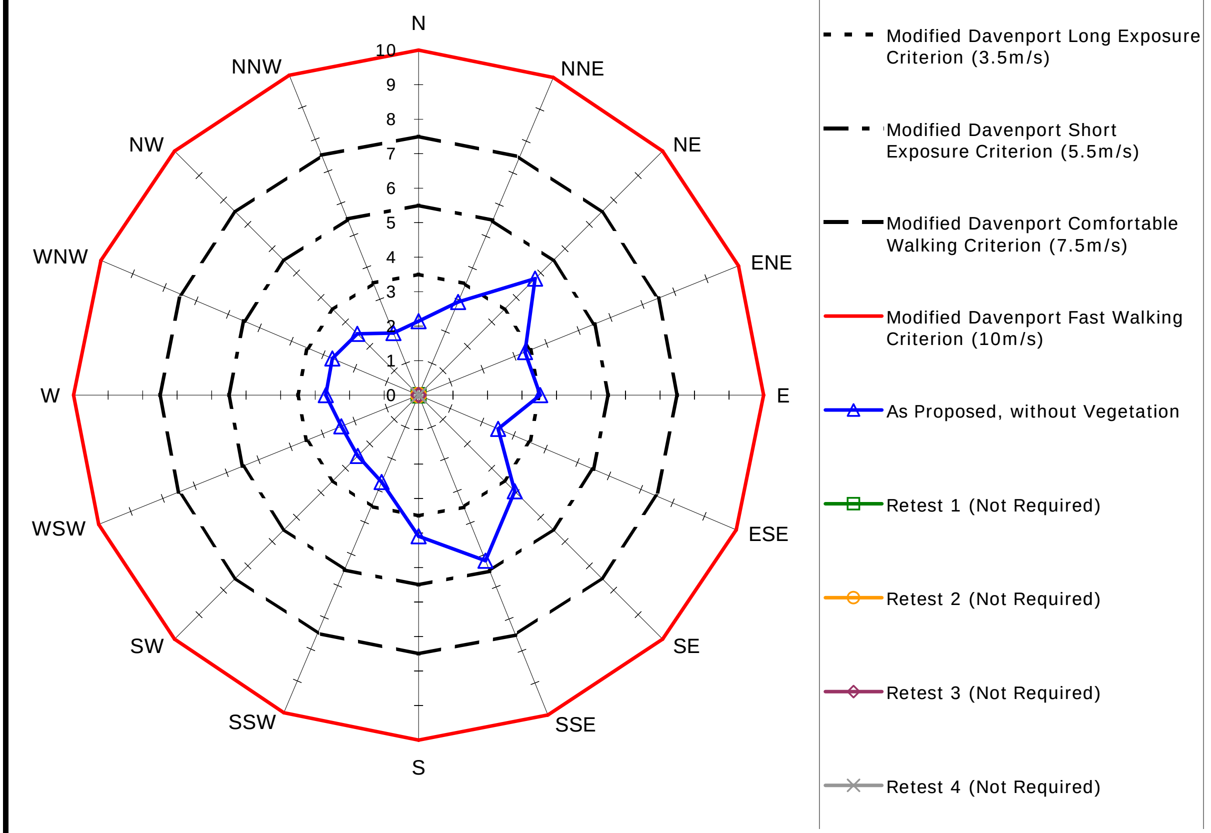


Annual Maximum Gust Wind Speeds (m/s)

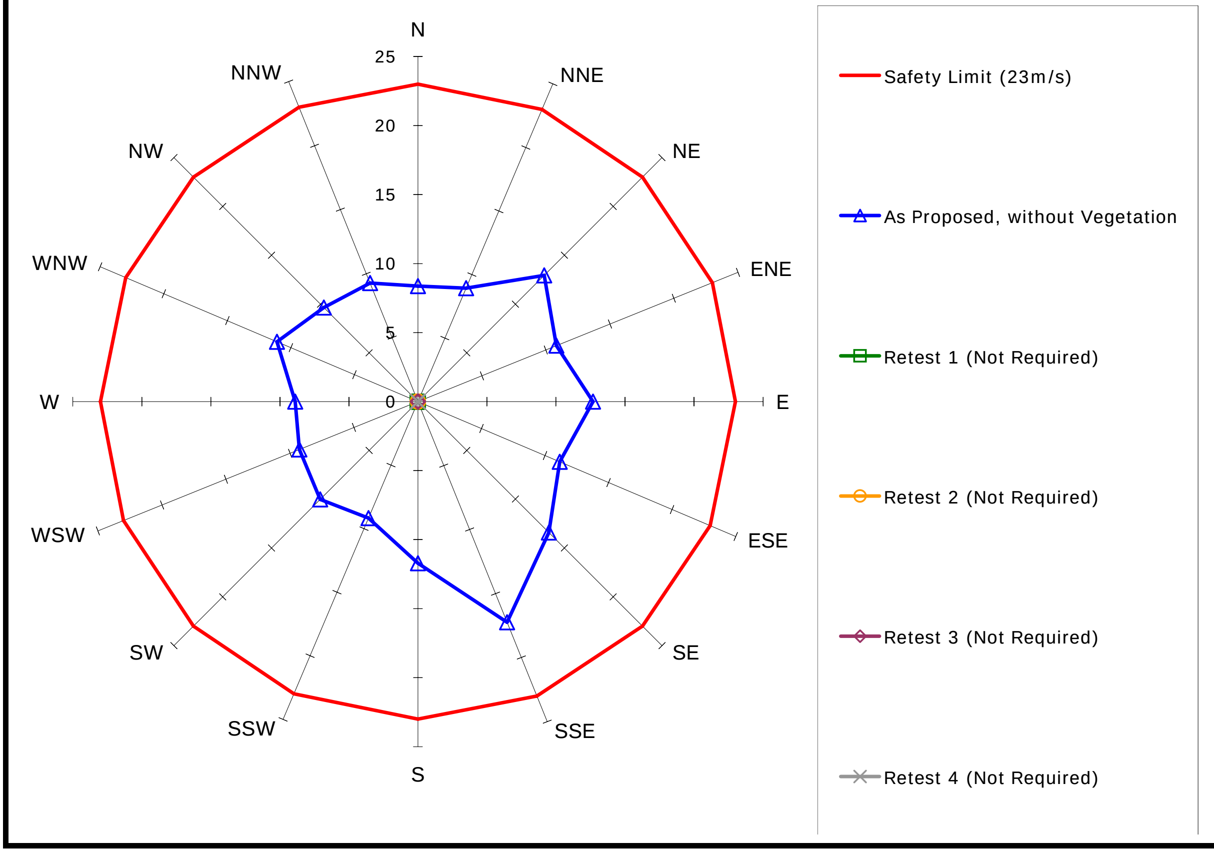


Measured Wind Speeds at Point 12

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

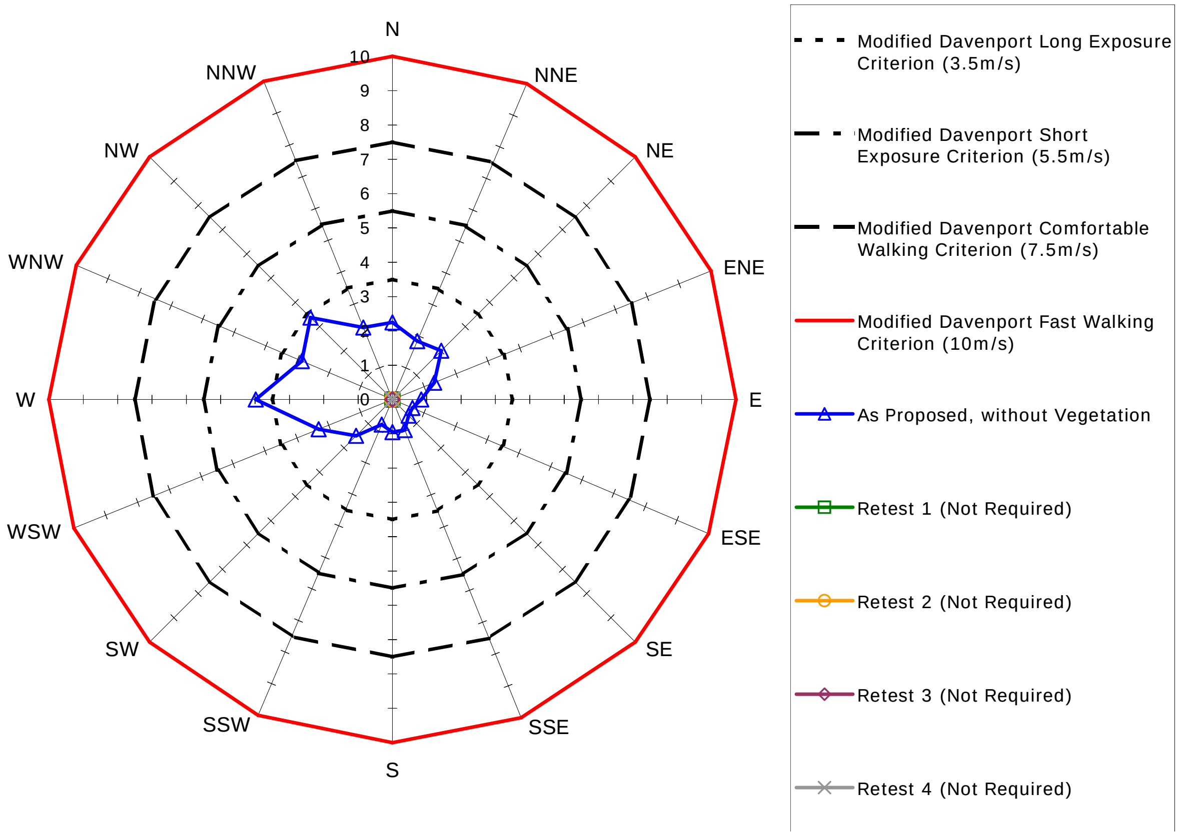


Annual Maximum Gust Wind Speeds (m/s)

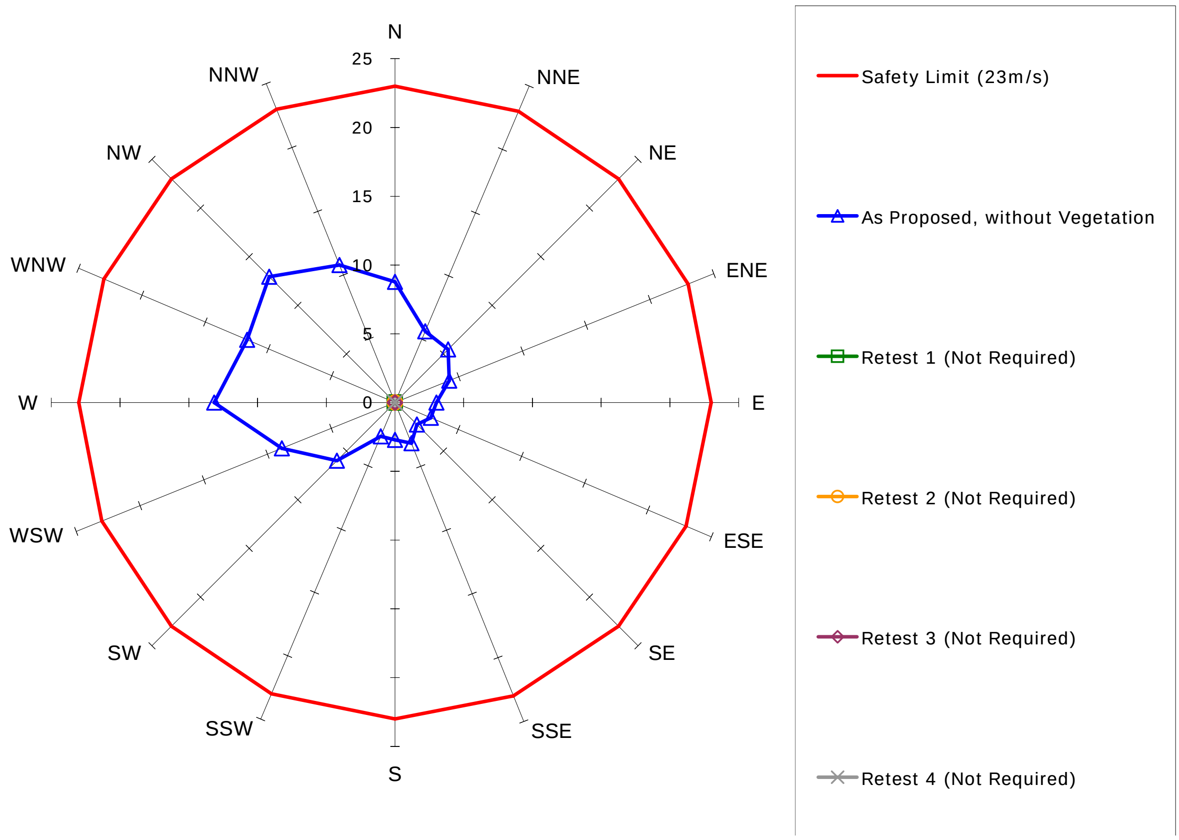


Measured Wind Speeds at Point 13

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

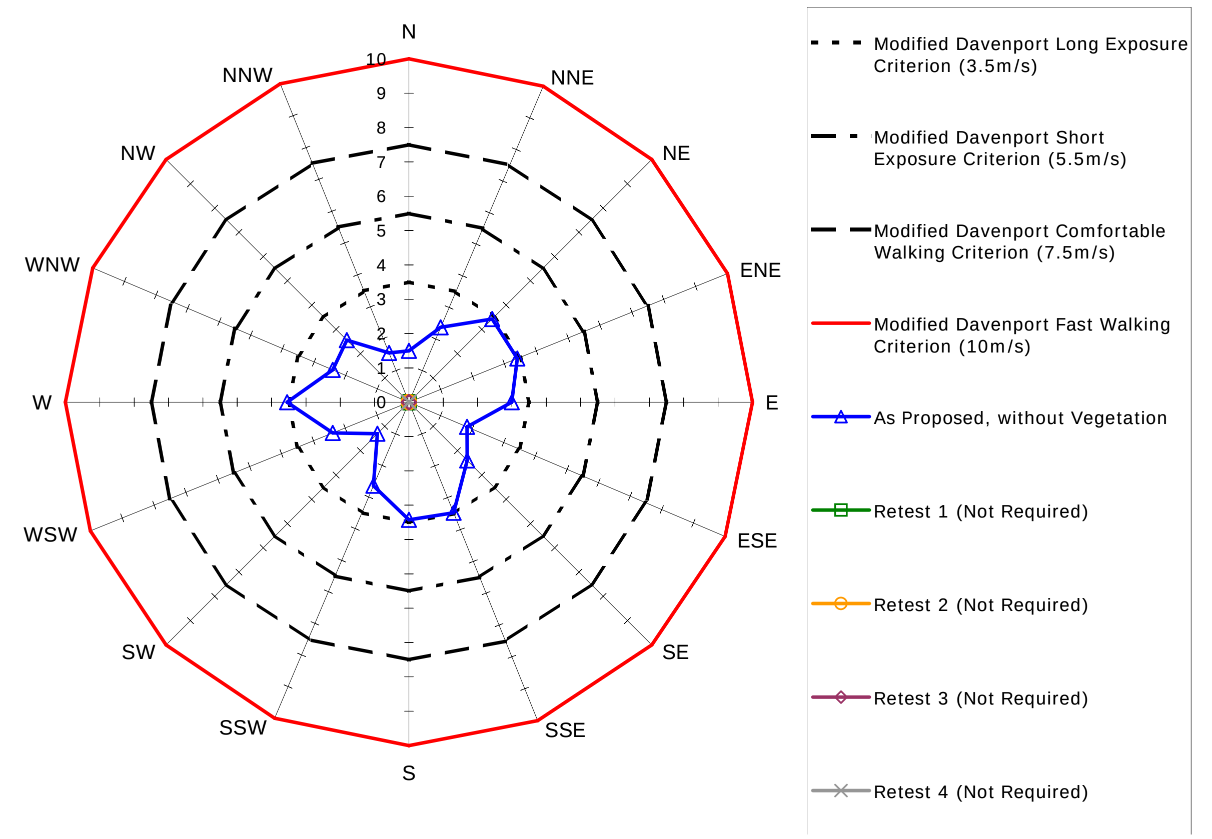


Annual Maximum Gust Wind Speeds (m/s)

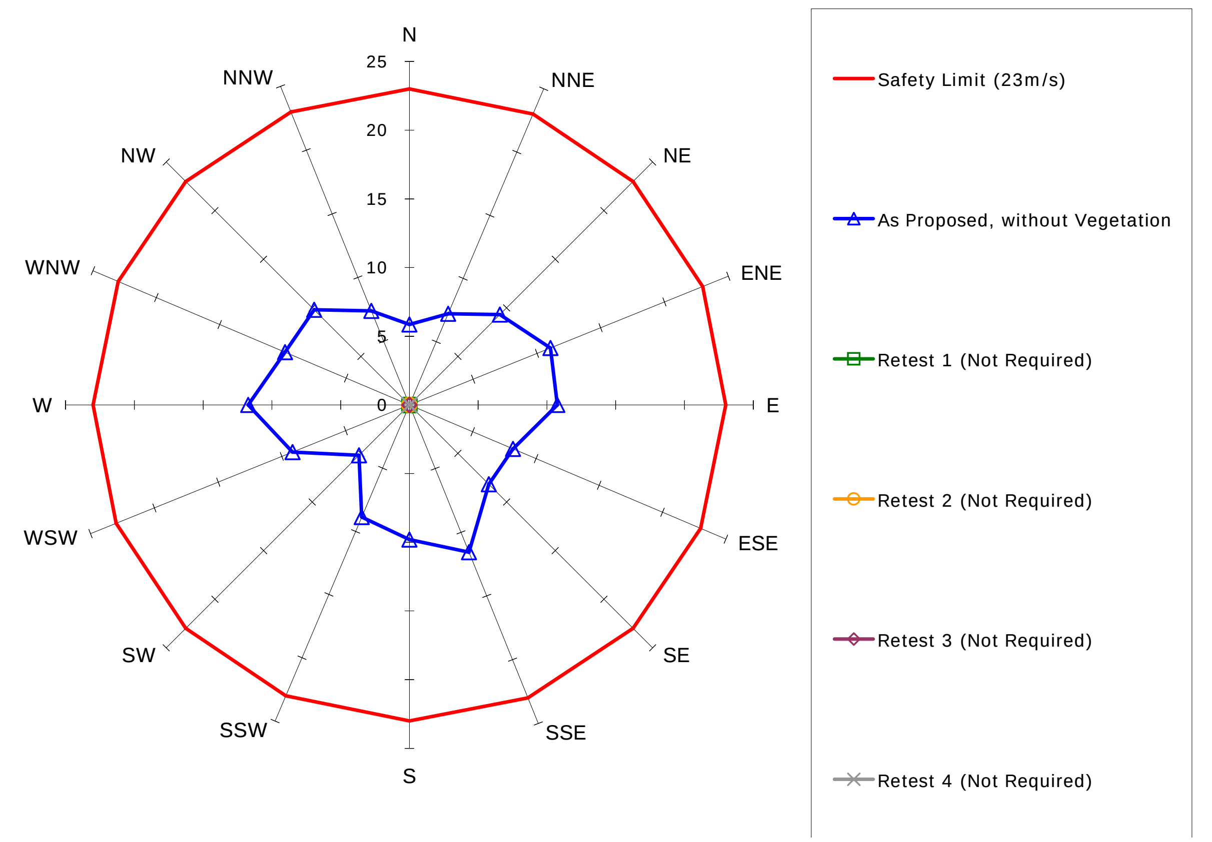


Measured Wind Speeds at Point 14

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

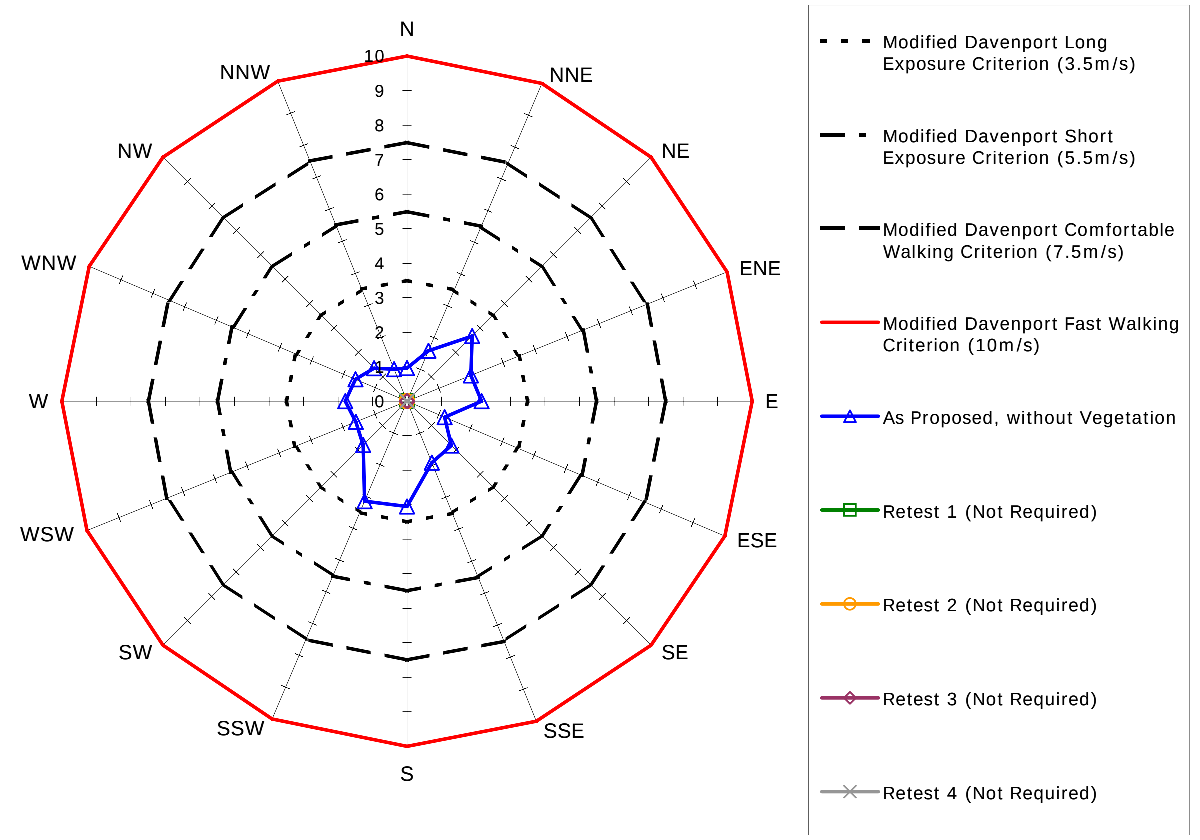


Annual Maximum Gust Wind Speeds (m/s)

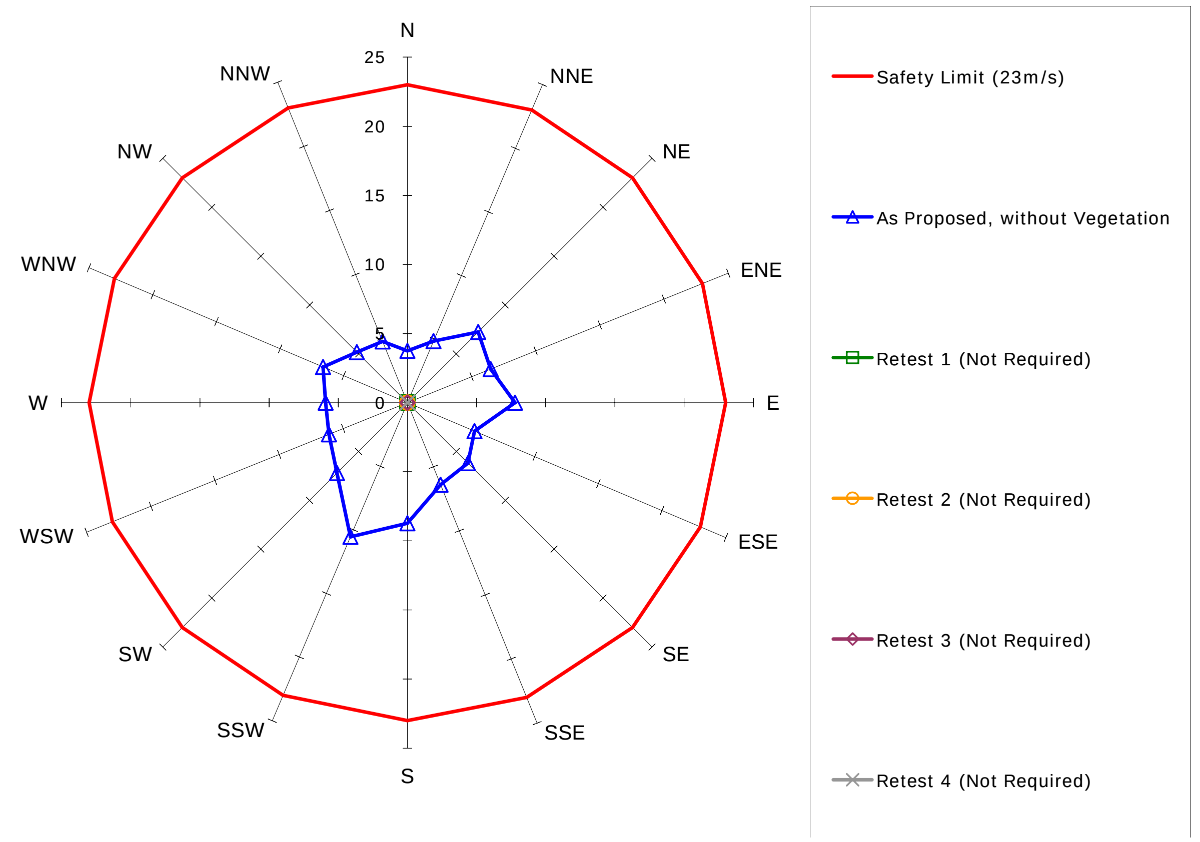


Measured Wind Speeds at Point 15

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

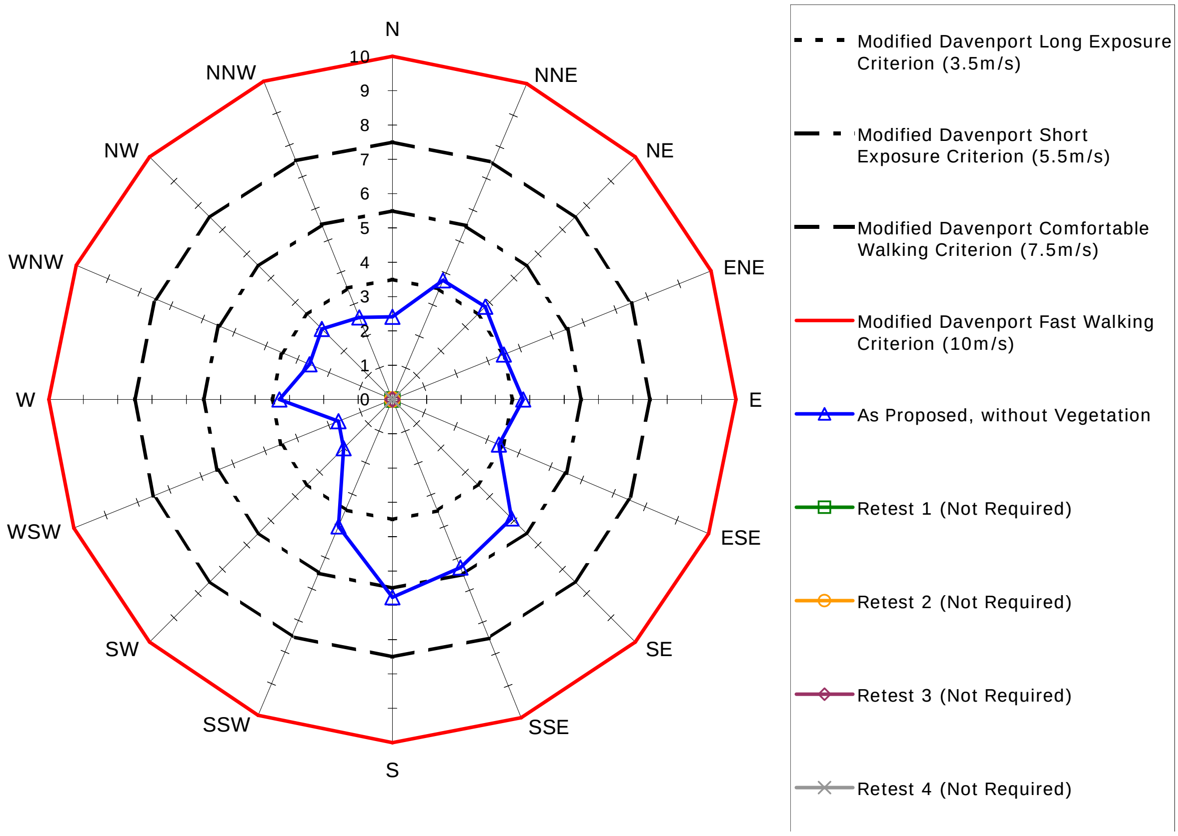


Annual Maximum Gust Wind Speeds (m/s)

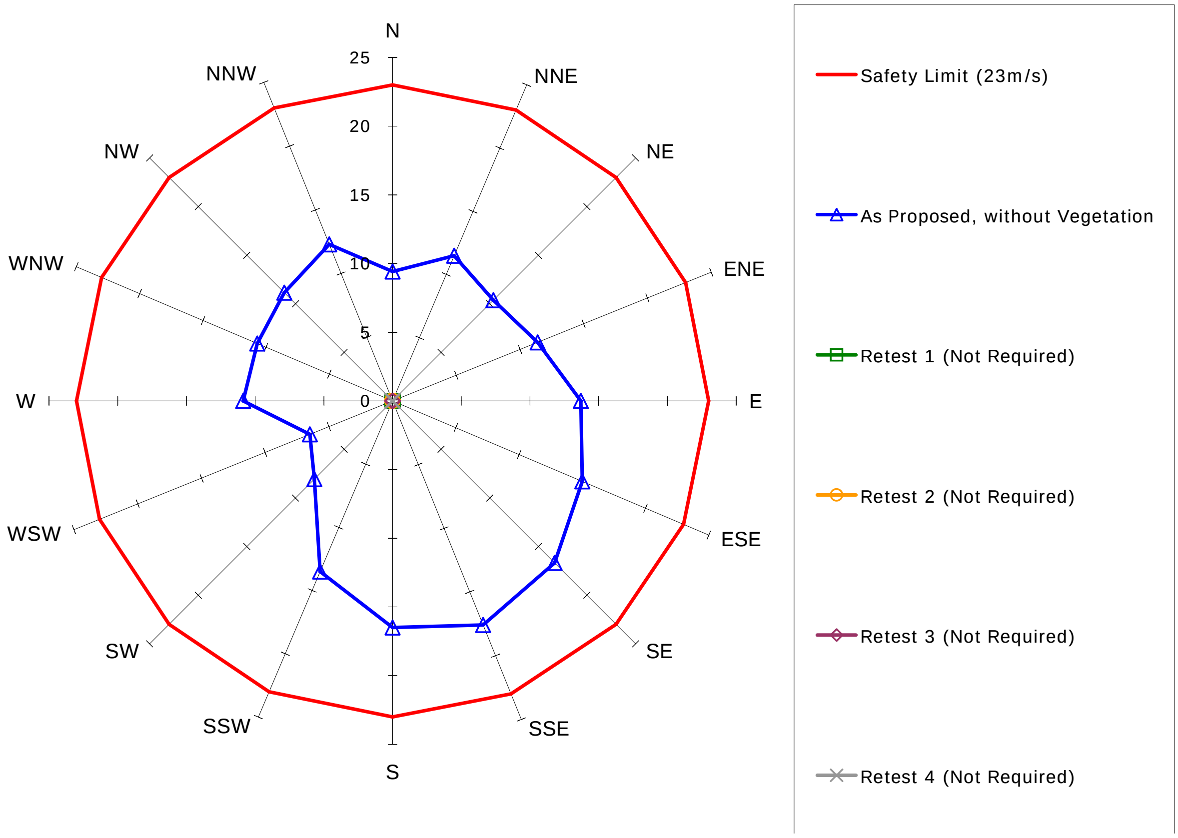


Measured Wind Speeds at Point 16

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

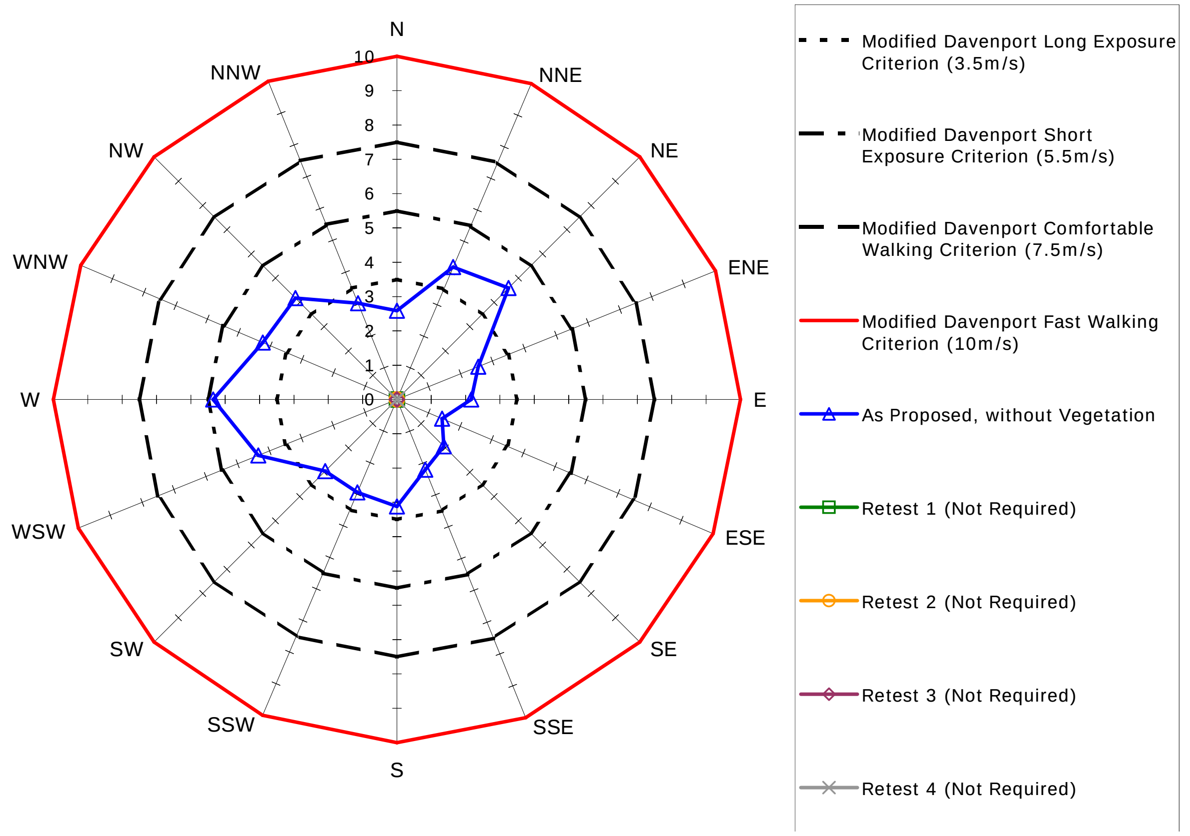


Annual Maximum Gust Wind Speeds (m/s)

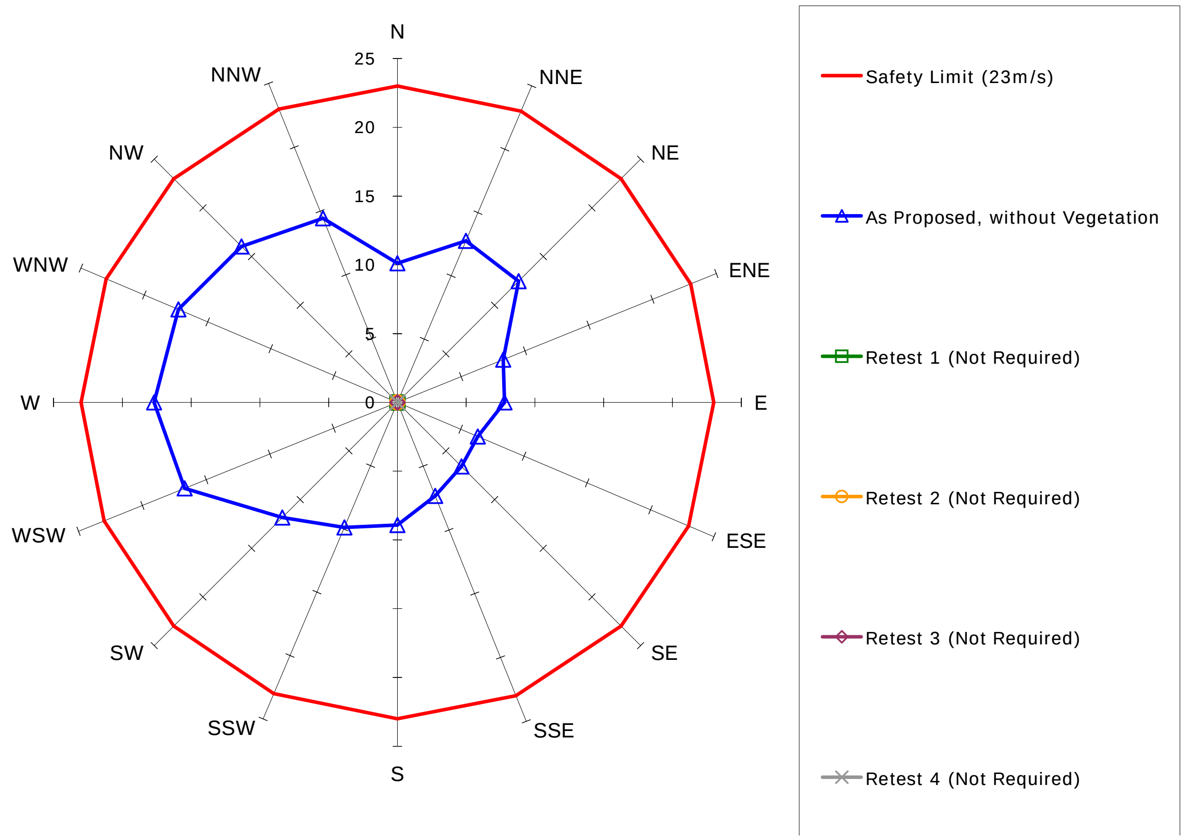


Measured Wind Speeds at Point 17

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

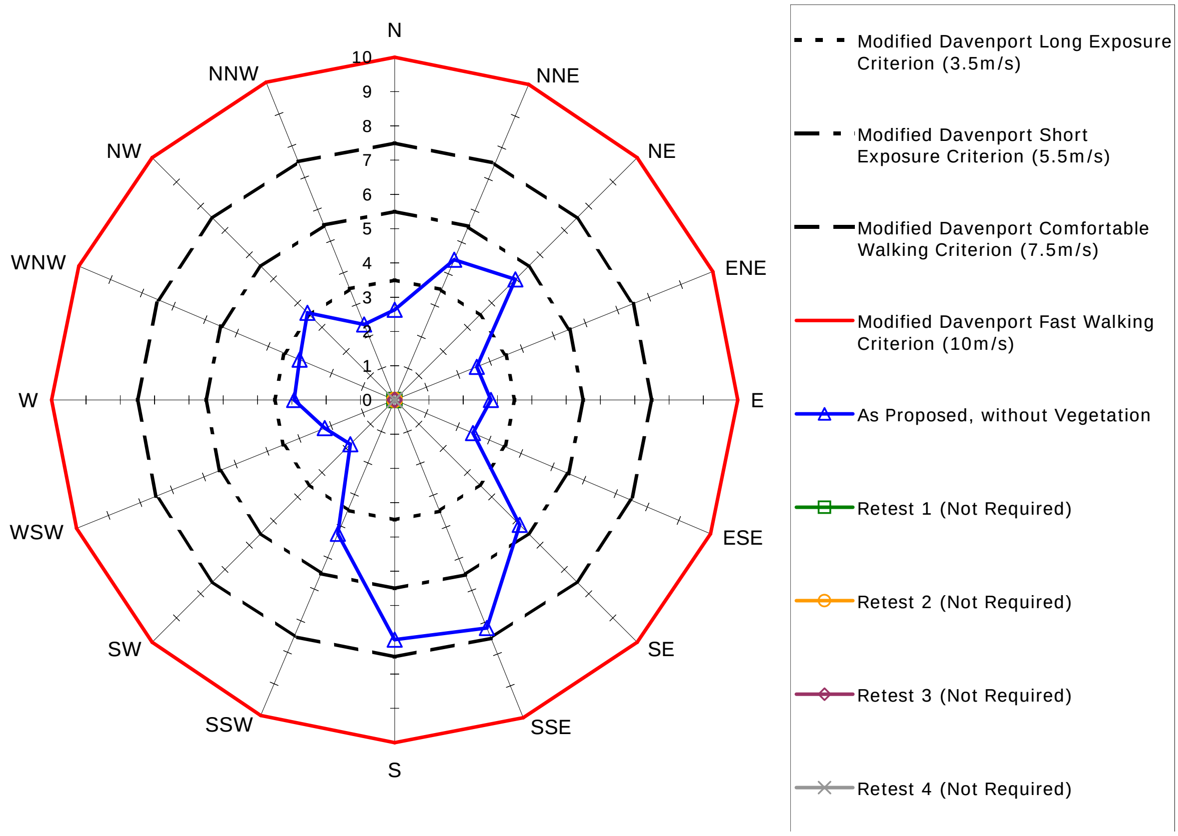


Annual Maximum Gust Wind Speeds (m/s)

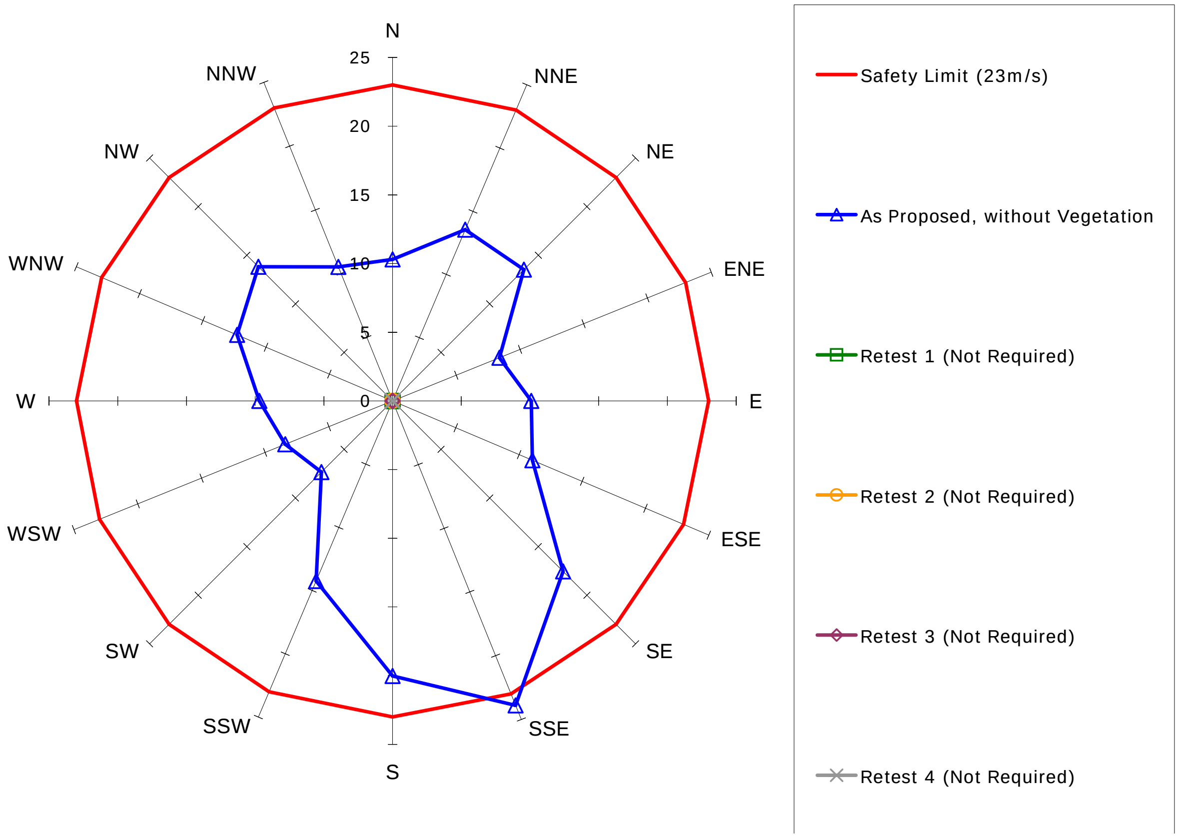


Measured Wind Speeds at Point 18

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

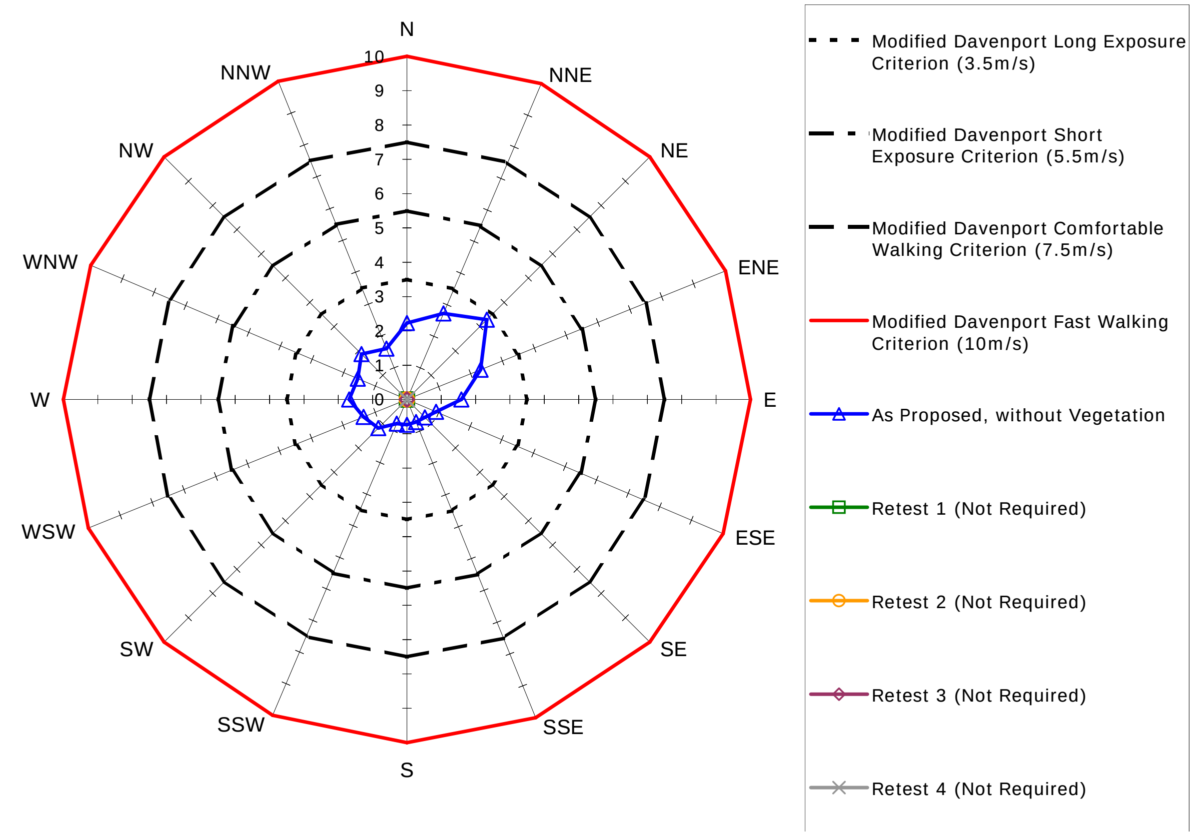


Annual Maximum Gust Wind Speeds (m/s)

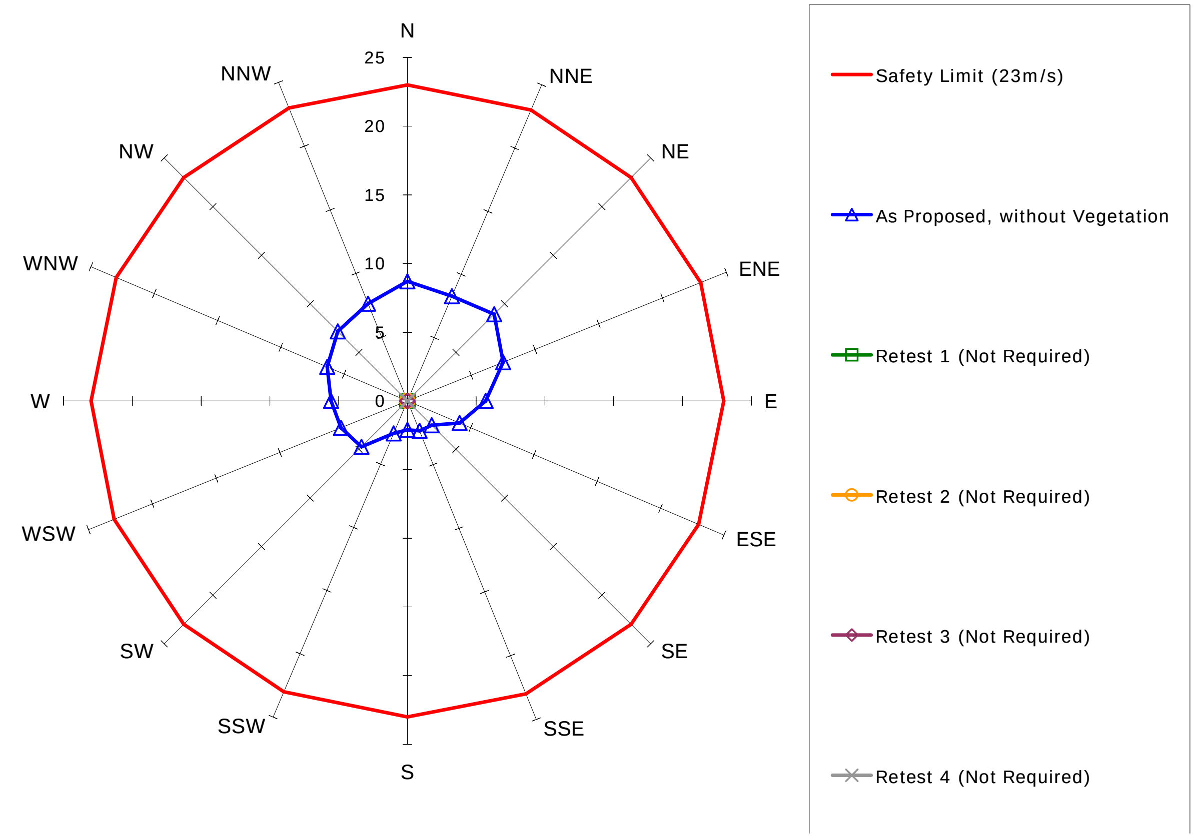


Measured Wind Speeds at Point 19

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

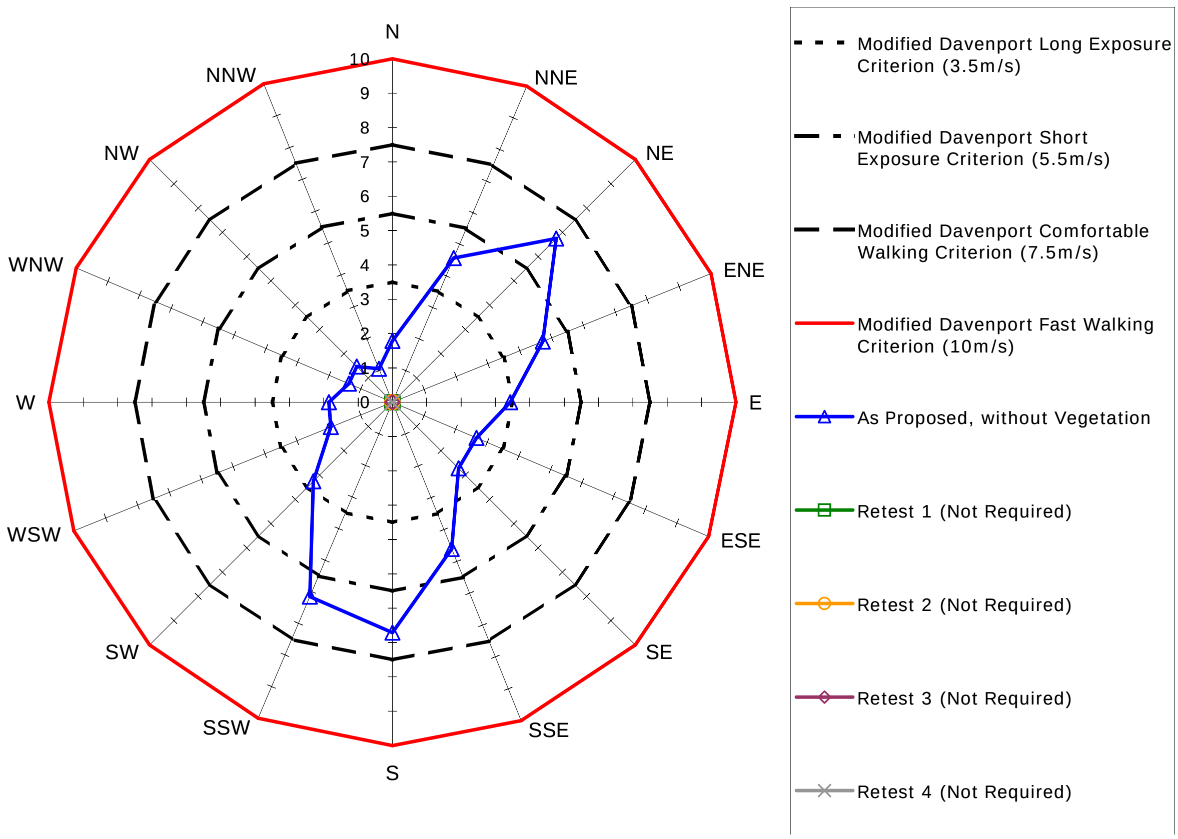


Annual Maximum Gust Wind Speeds (m/s)

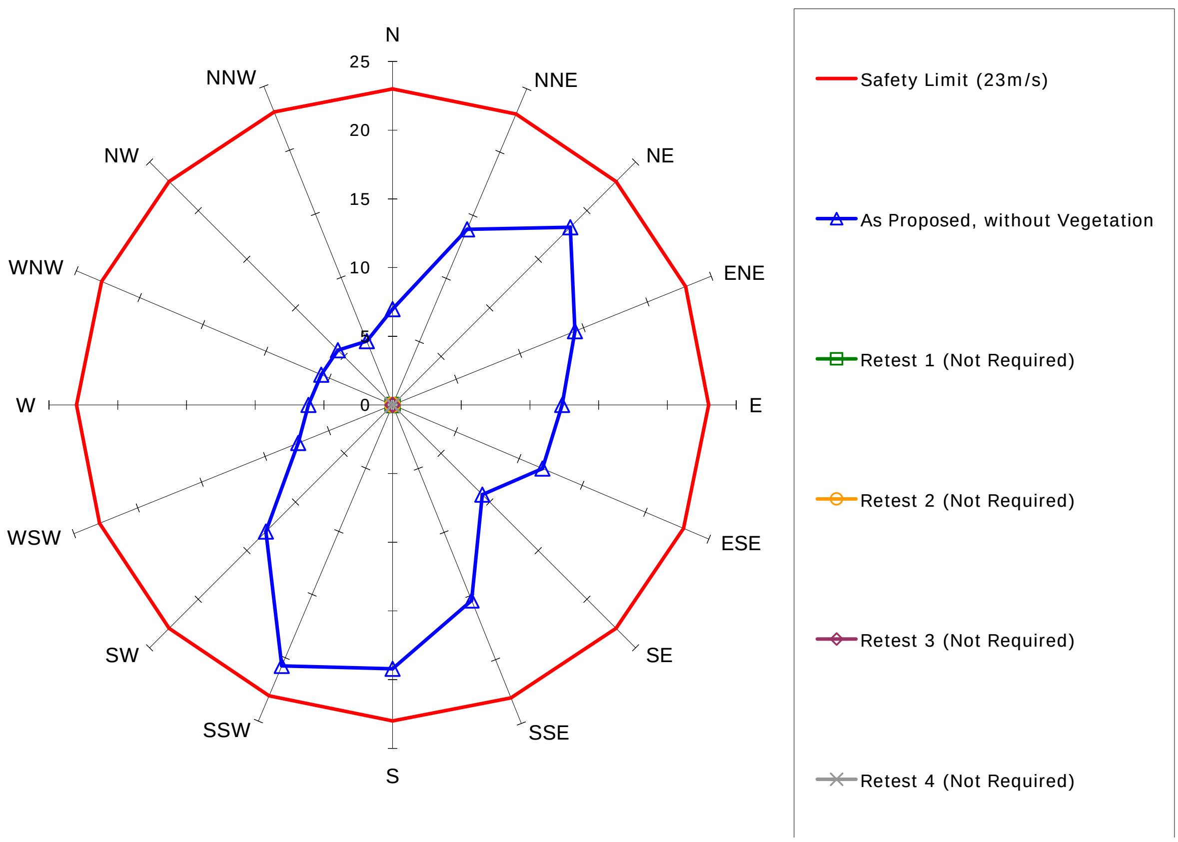


Measured Wind Speeds at Point 20

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

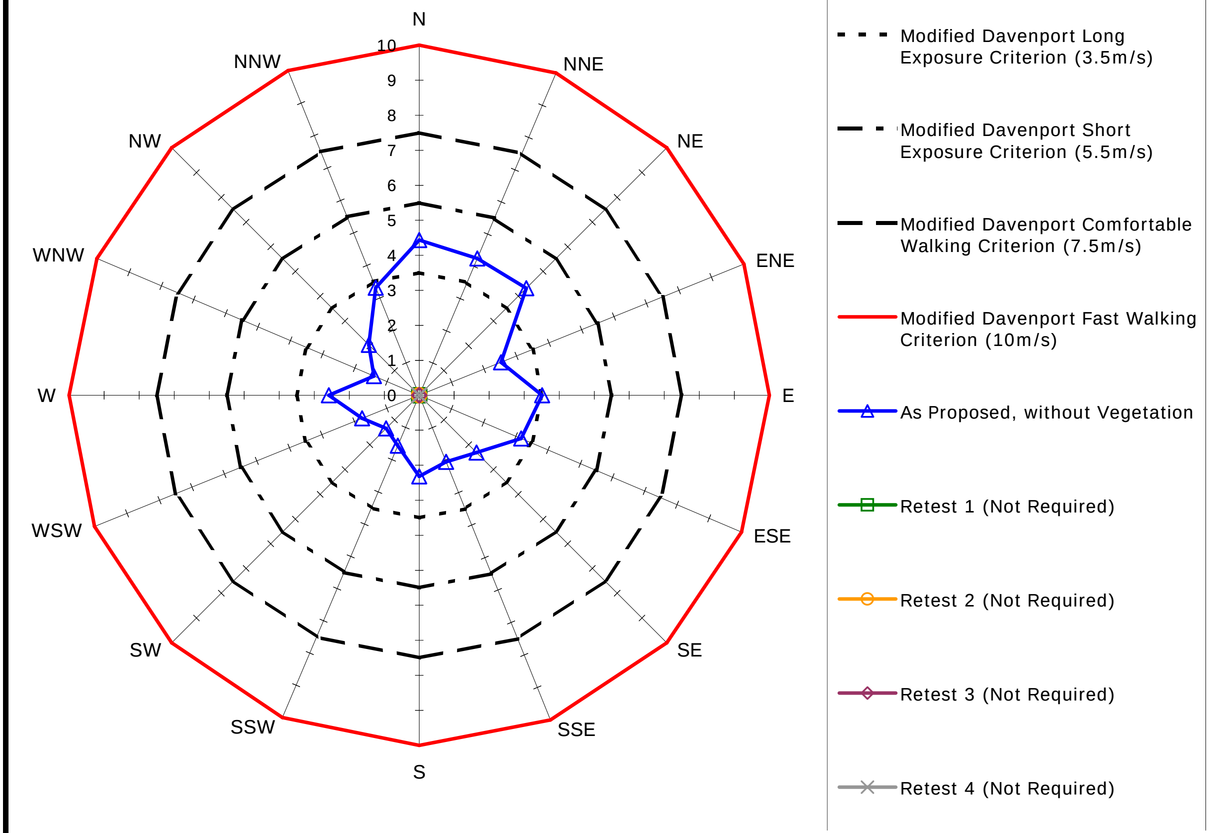


Annual Maximum Gust Wind Speeds (m/s)

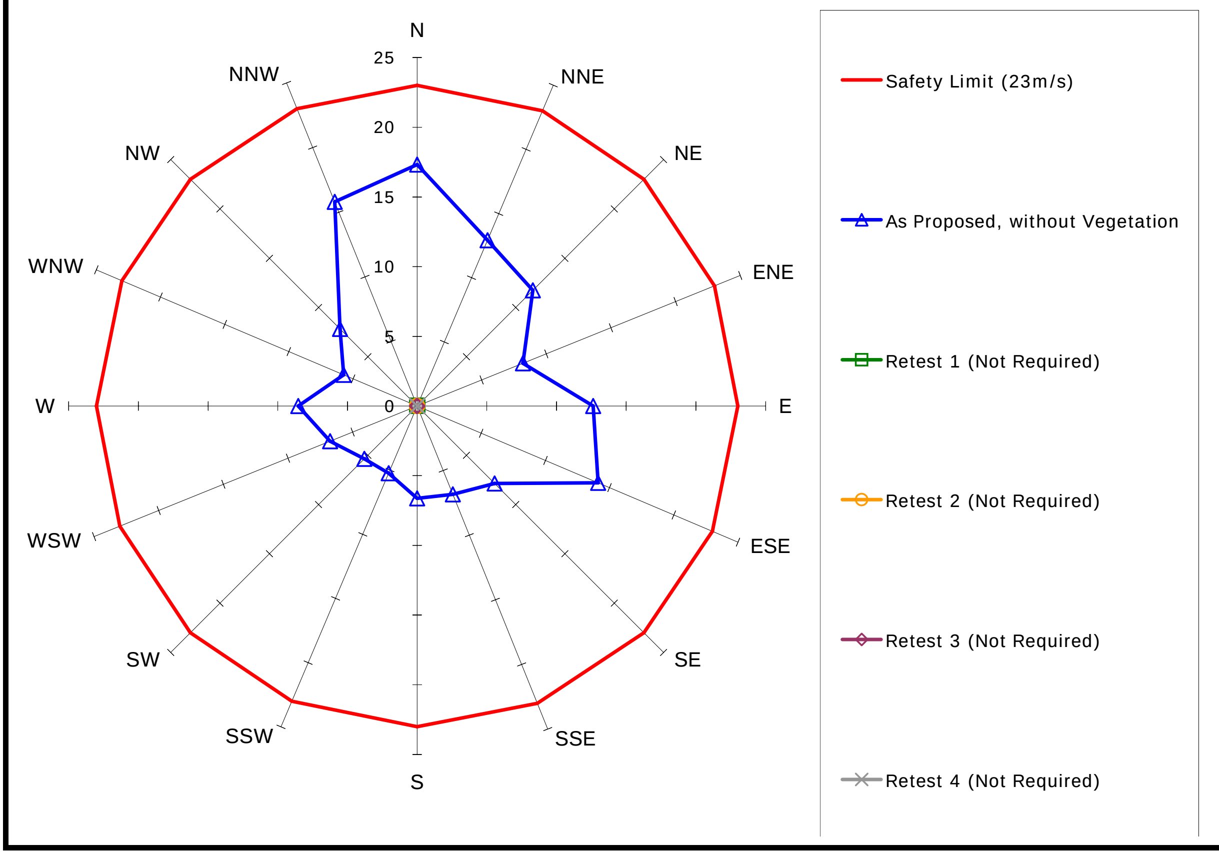


Measured Wind Speeds at Point 21

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

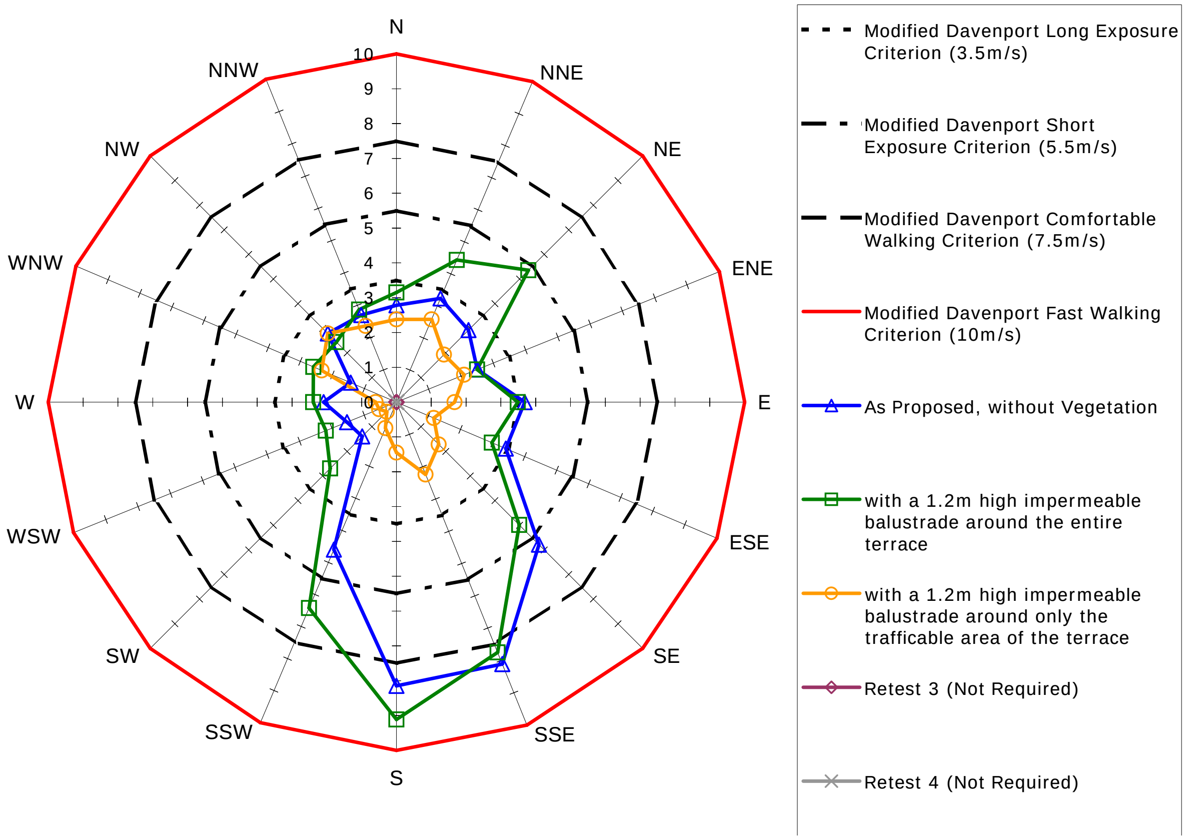


Annual Maximum Gust Wind Speeds (m/s)

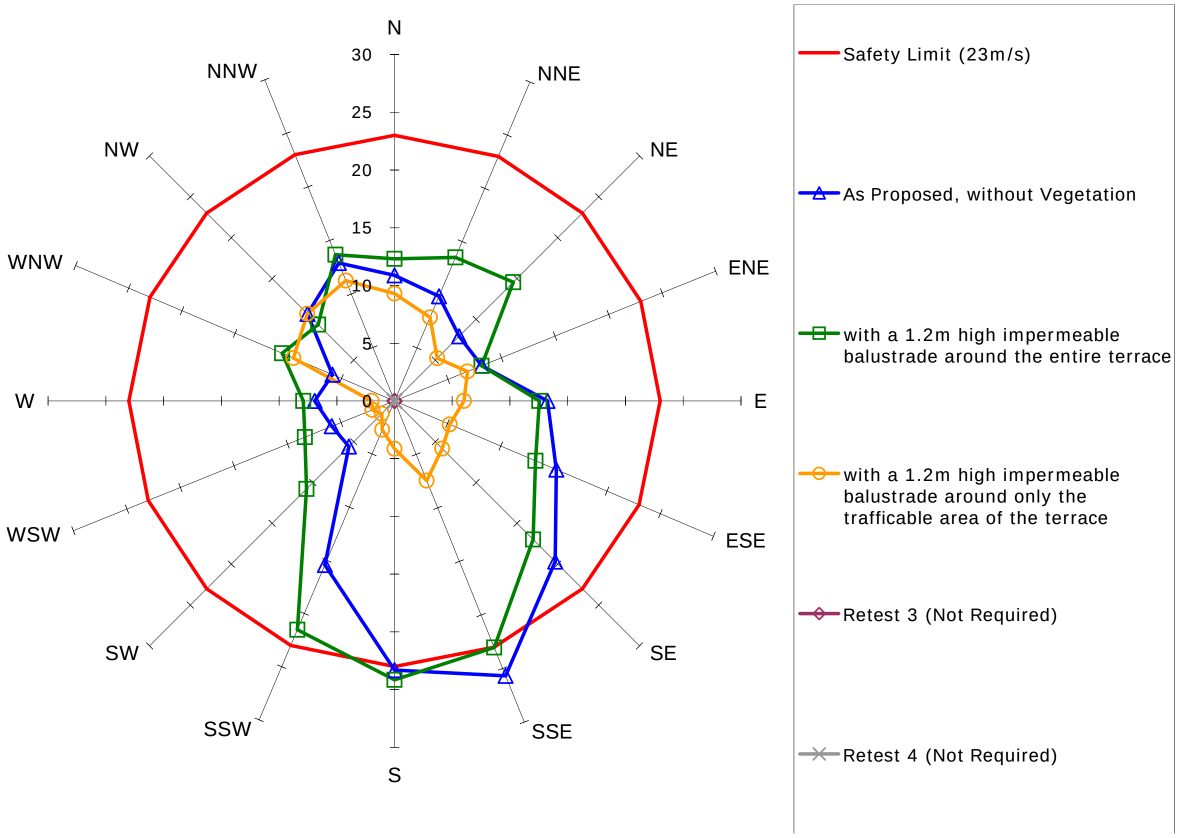


Measured Wind Speeds at Point 22

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

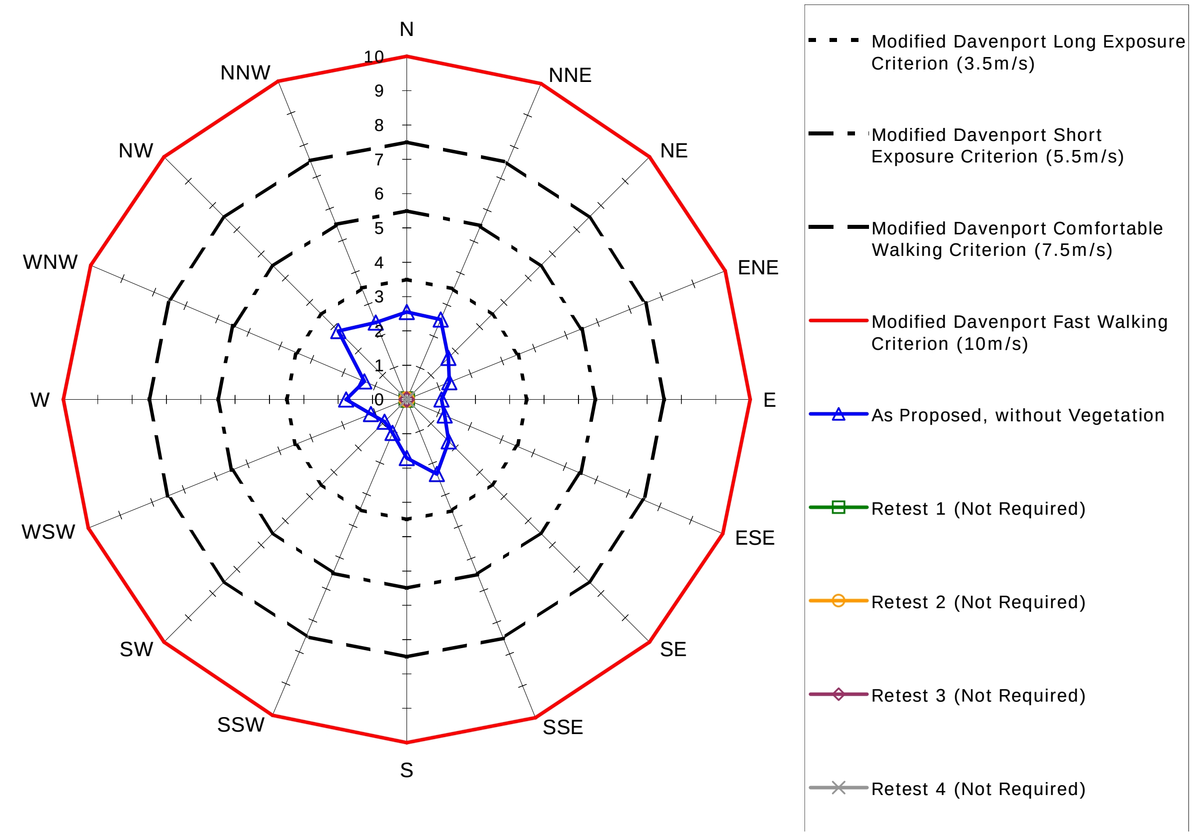


Annual Maximum Gust Wind Speeds (m/s)

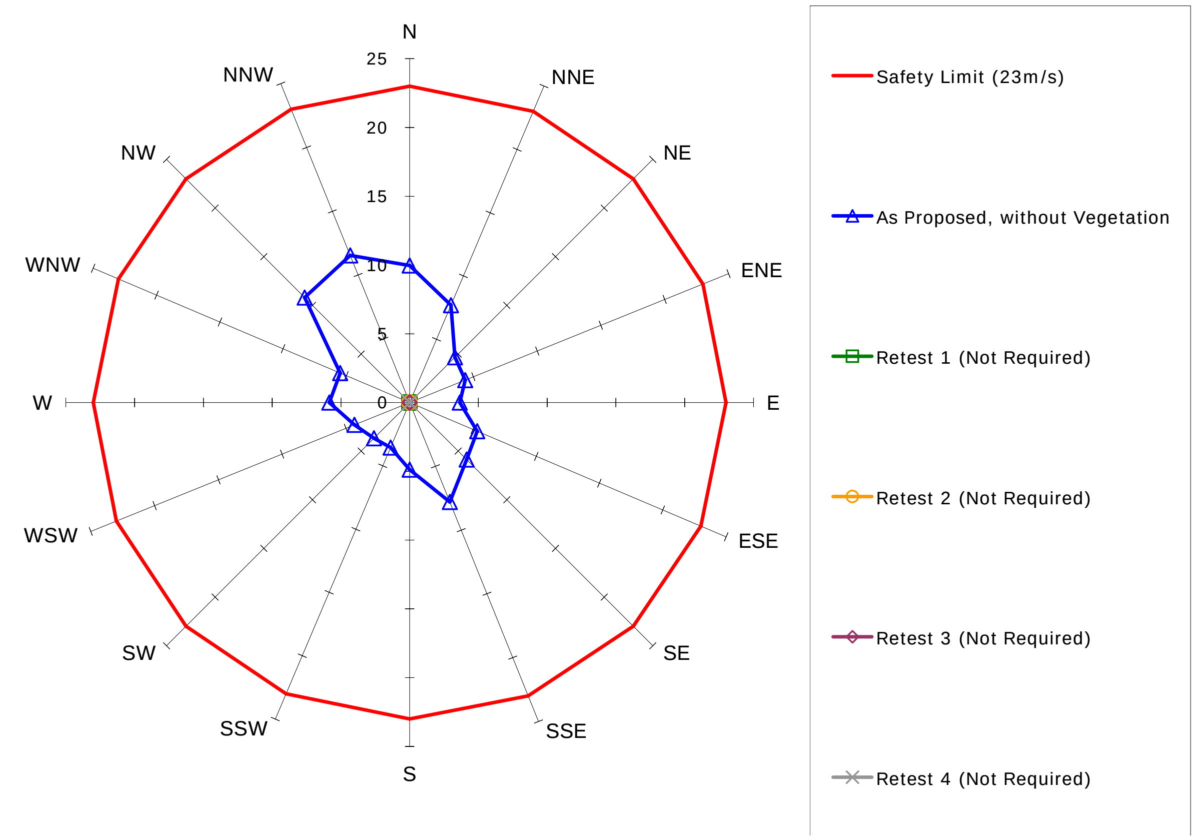


Measured Wind Speeds at Point 23

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

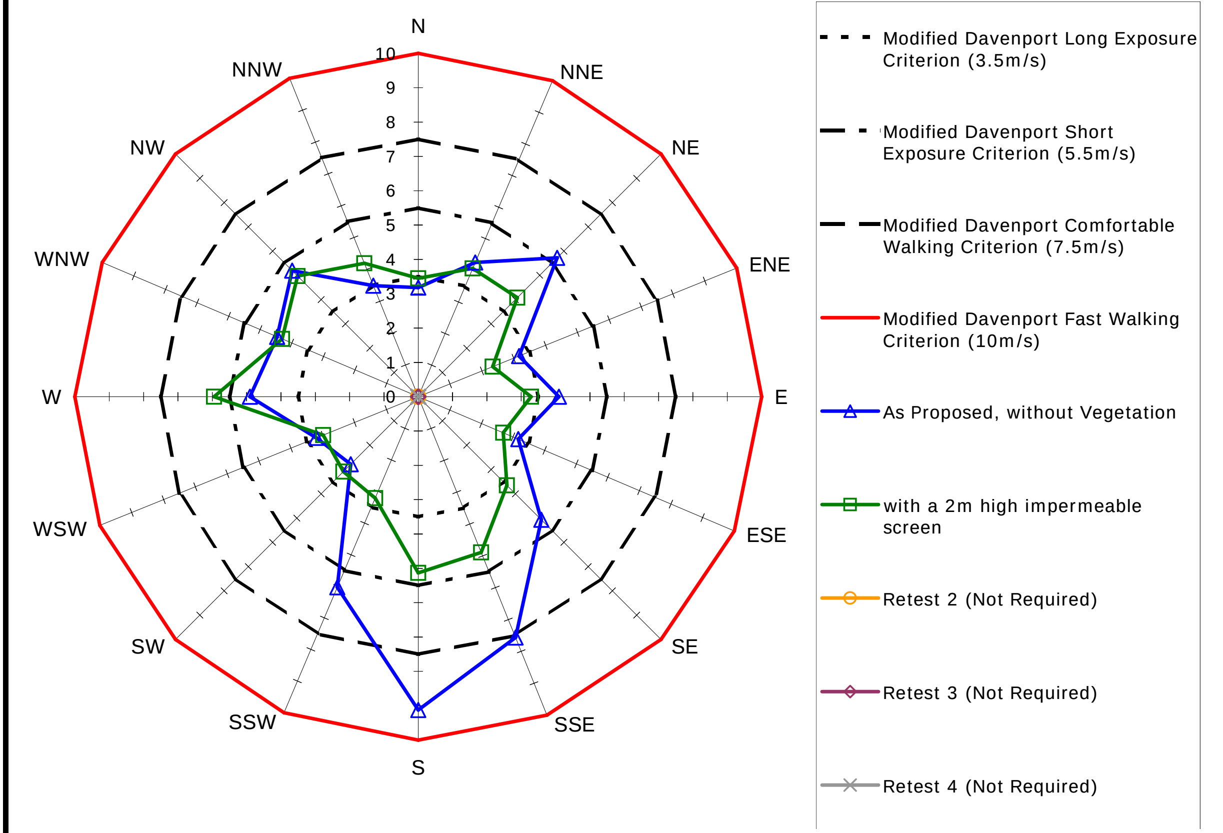


Annual Maximum Gust Wind Speeds (m/s)

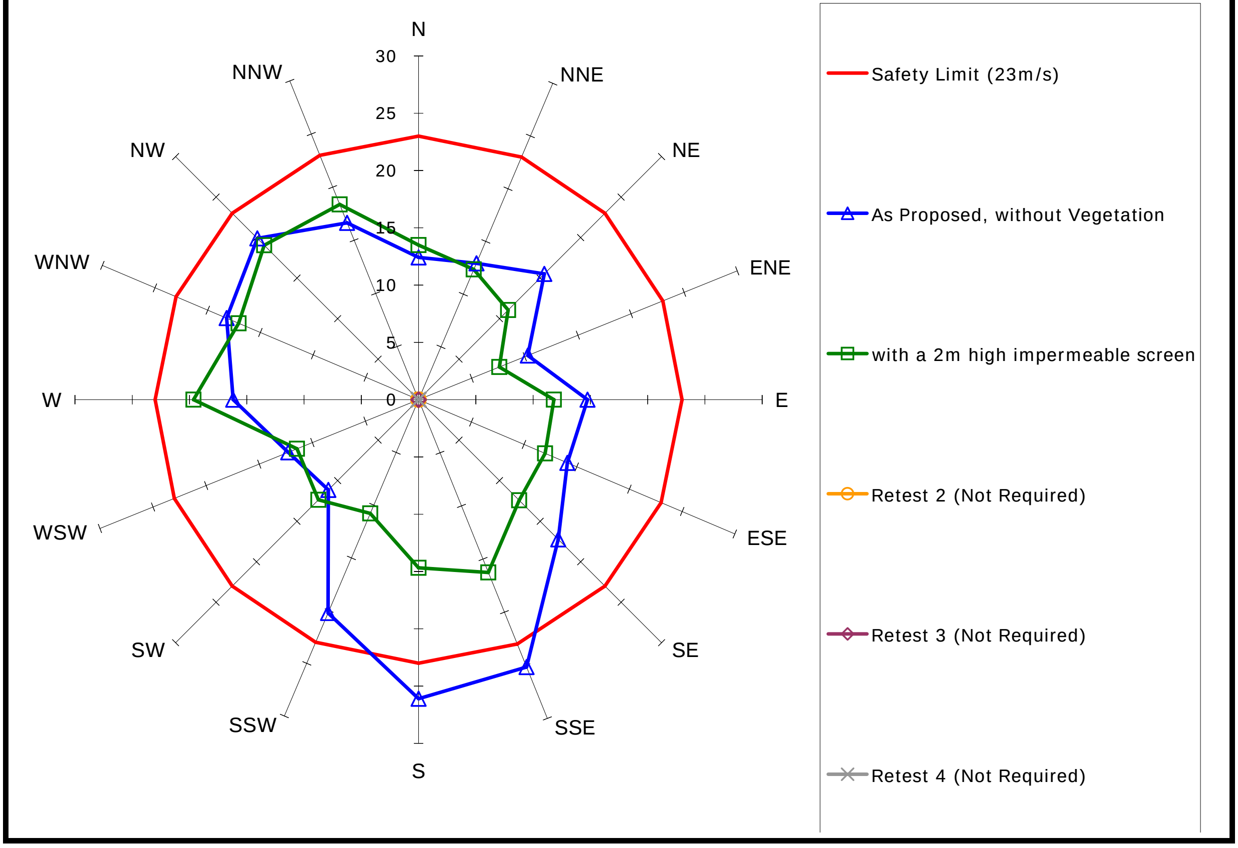


Measured Wind Speeds at Point 24

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

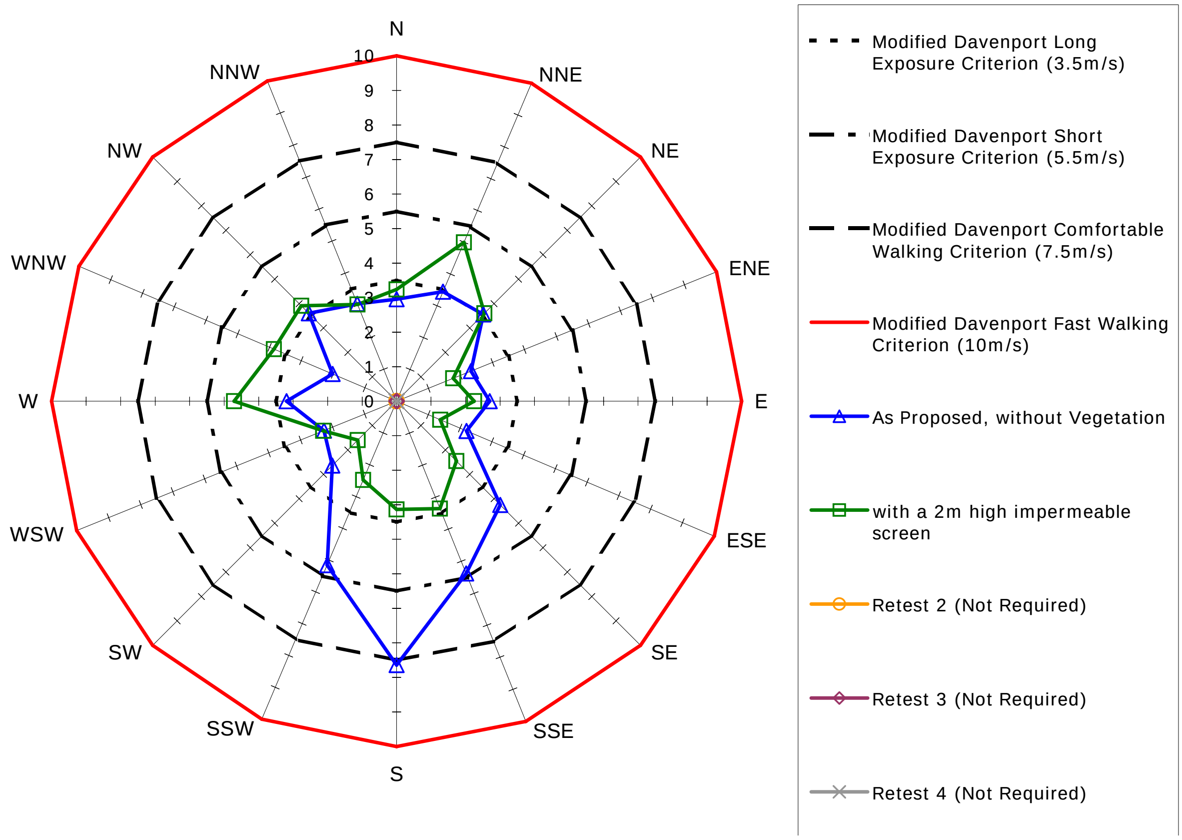


Annual Maximum Gust Wind Speeds (m/s)

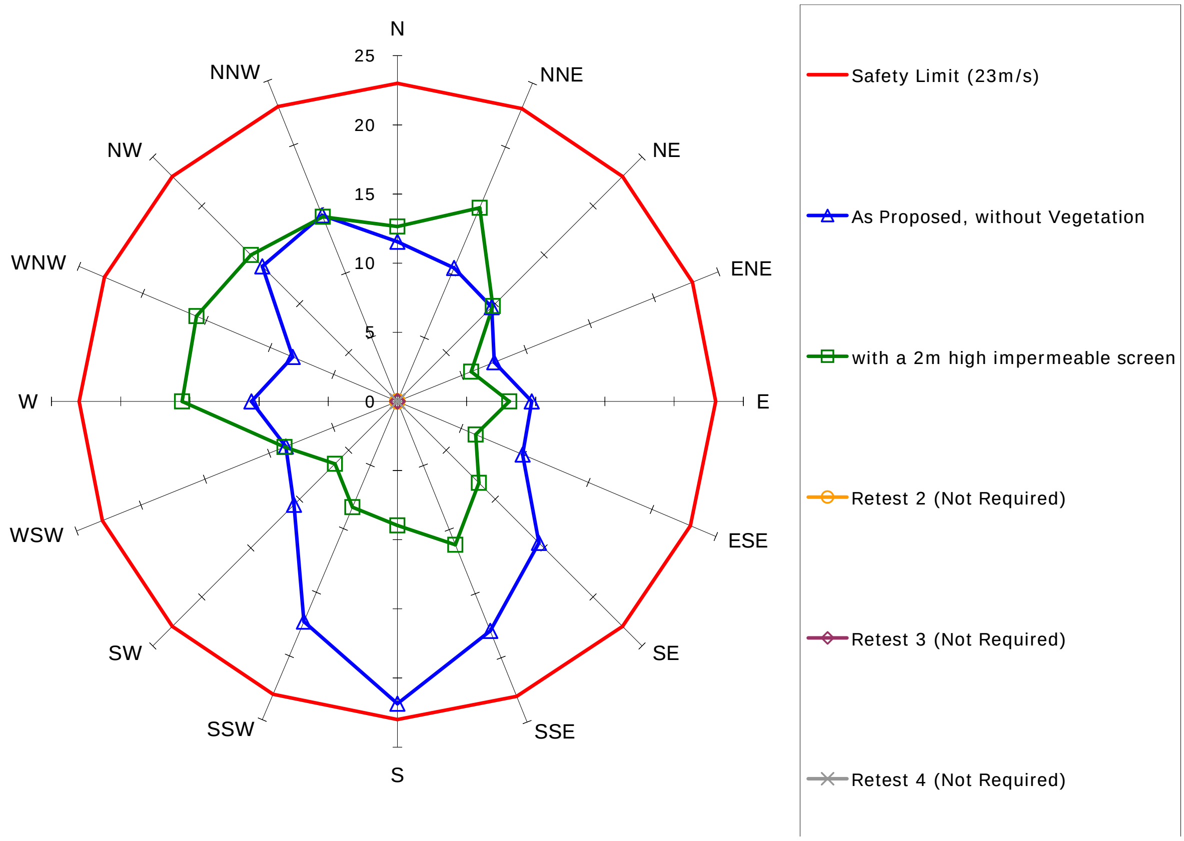


Measured Wind Speeds at Point 25

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

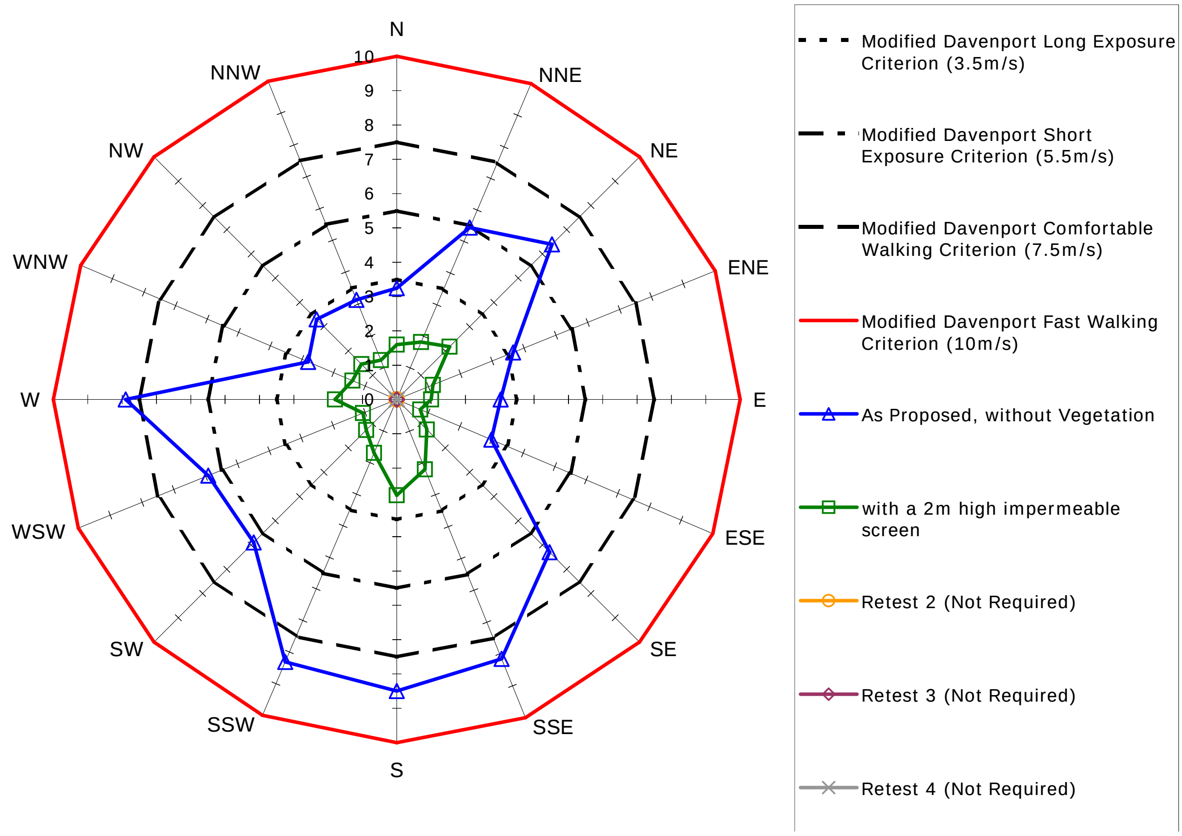


Annual Maximum Gust Wind Speeds (m/s)

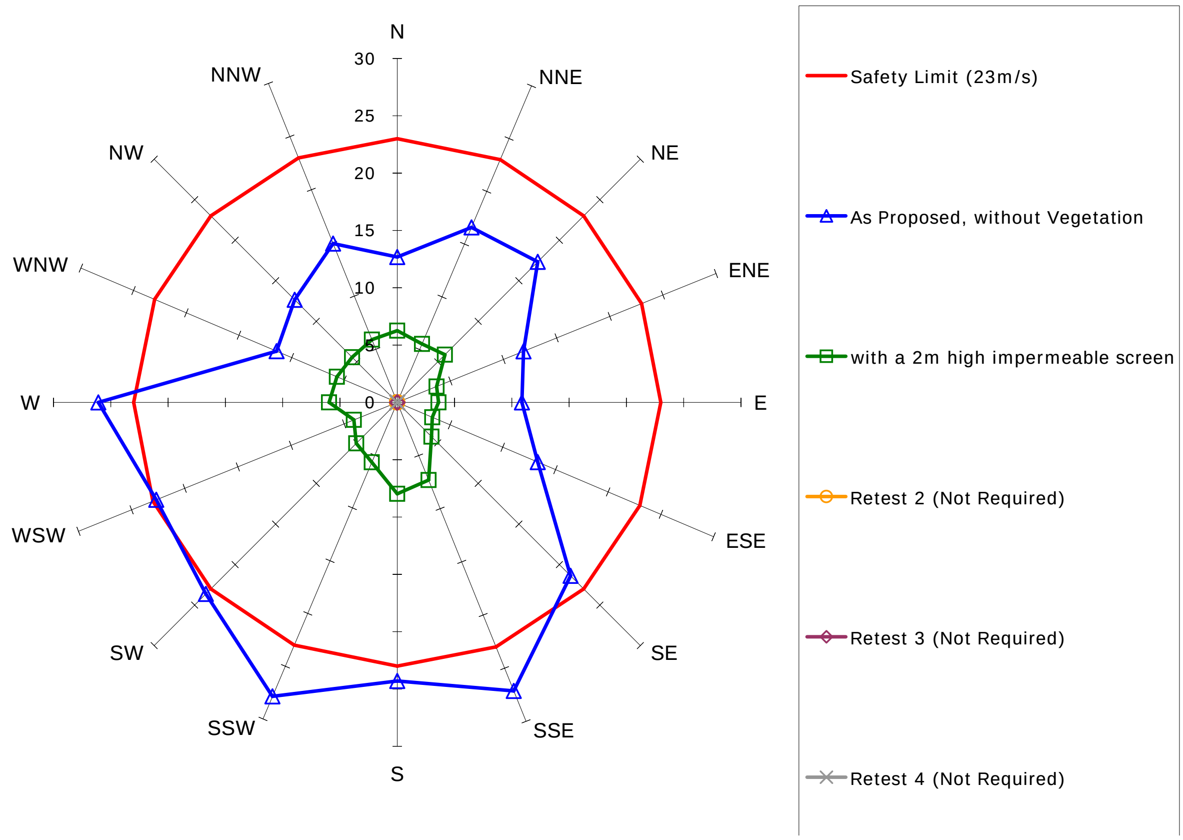


Measured Wind Speeds at Point 26

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

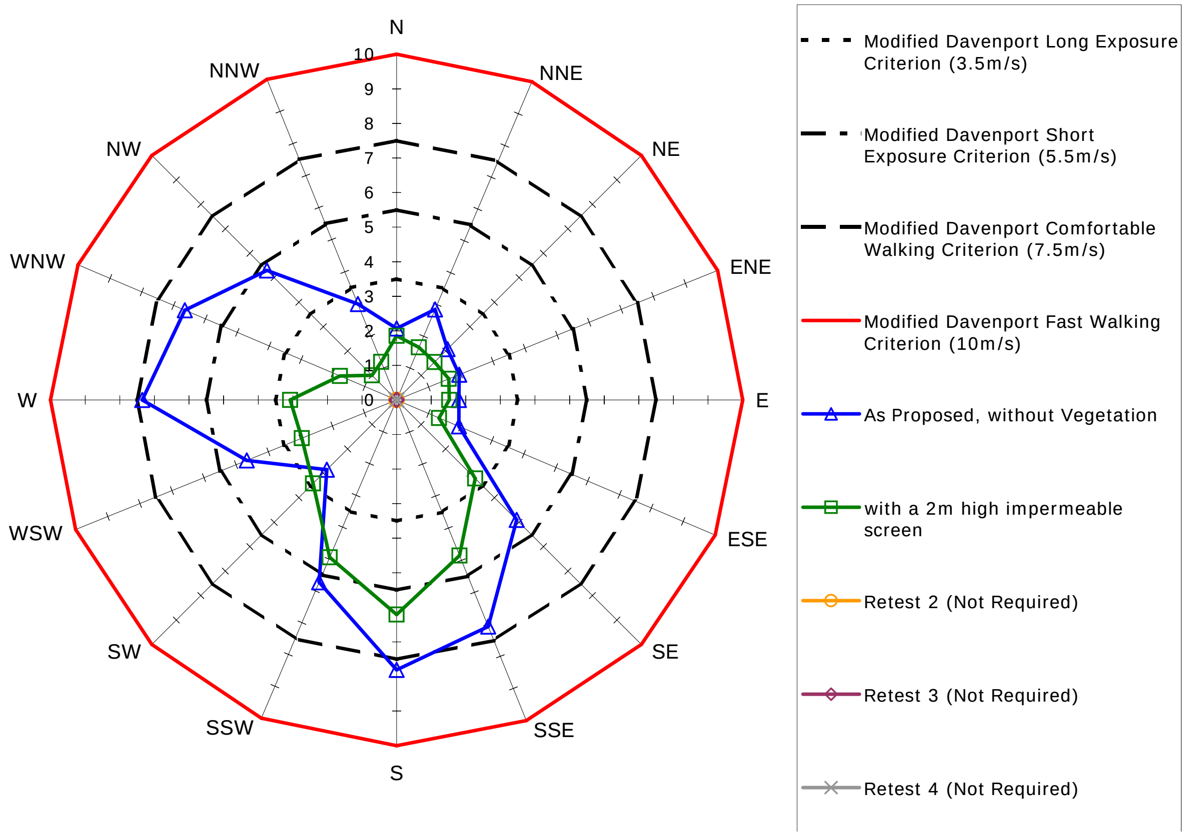


Annual Maximum Gust Wind Speeds (m/s)

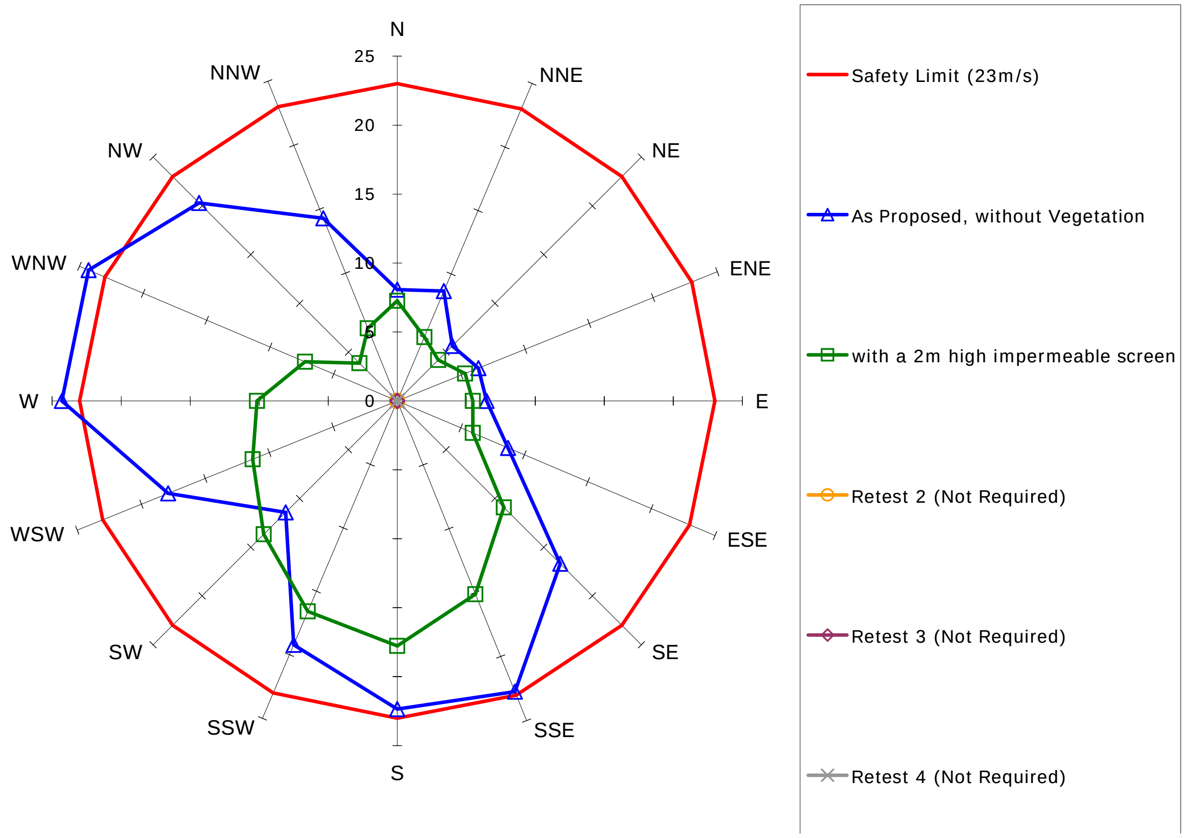


Measured Wind Speeds at Point 27

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

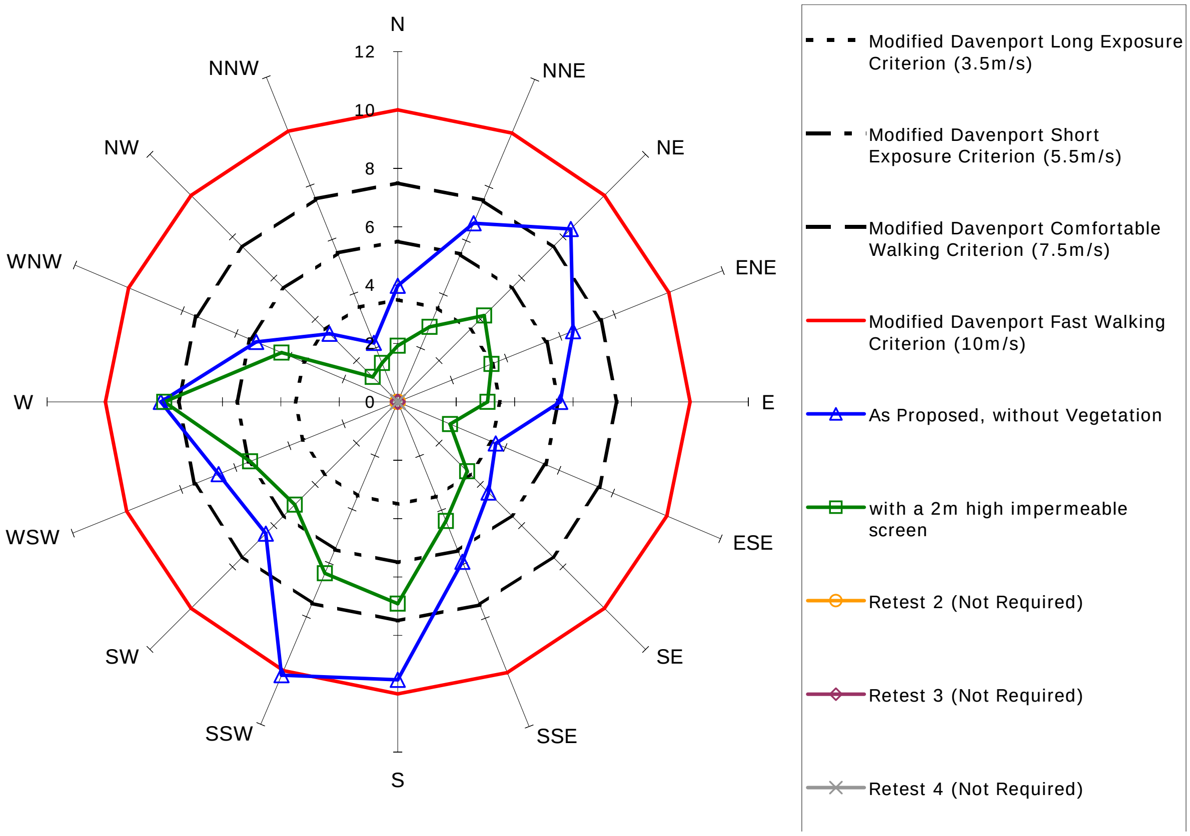


Annual Maximum Gust Wind Speeds (m/s)

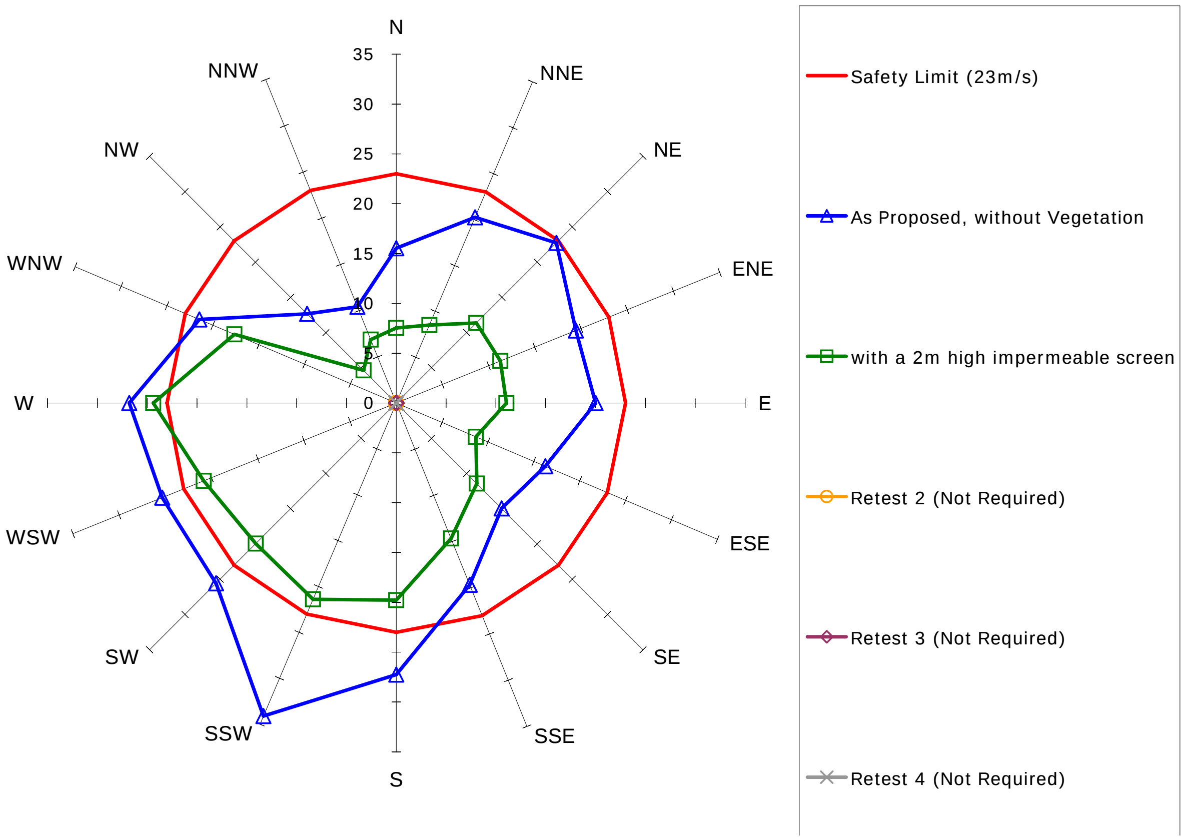


Measured Wind Speeds at Point 28

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

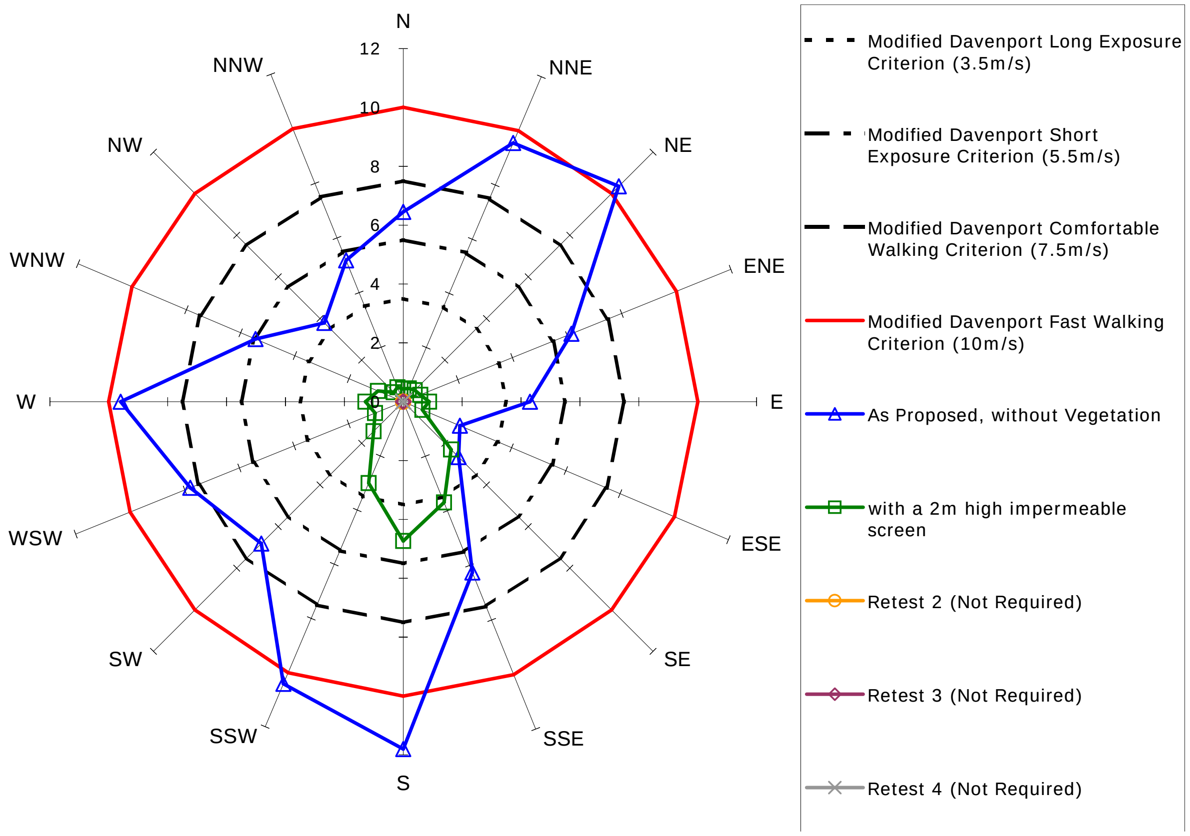


Annual Maximum Gust Wind Speeds (m/s)

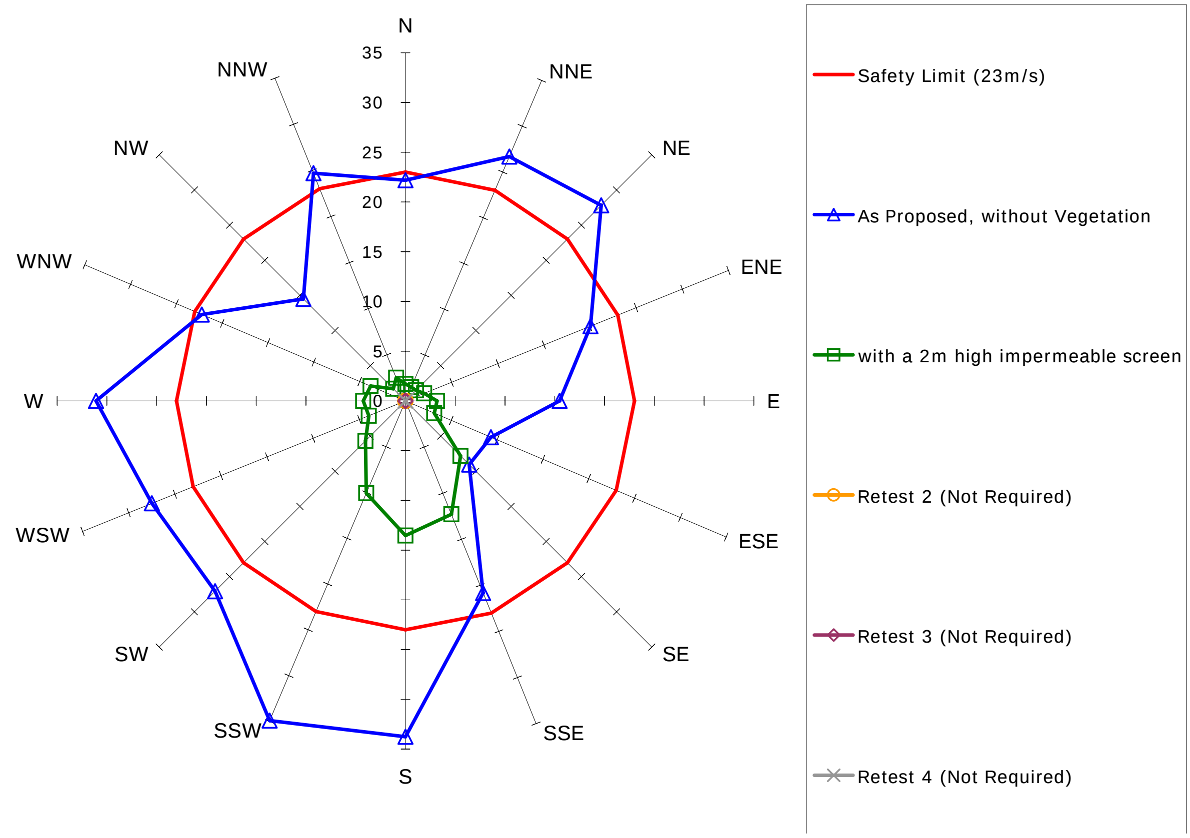


Measured Wind Speeds at Point 29

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

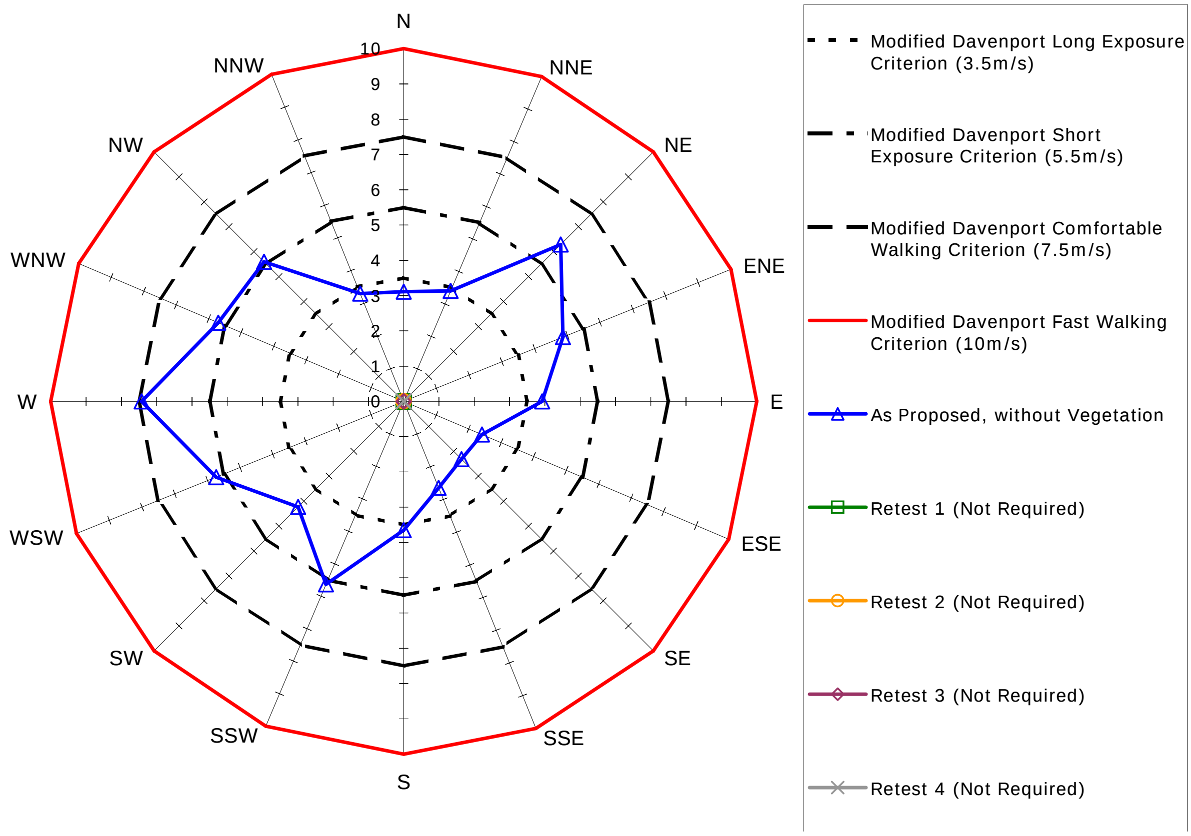


Annual Maximum Gust Wind Speeds (m/s)

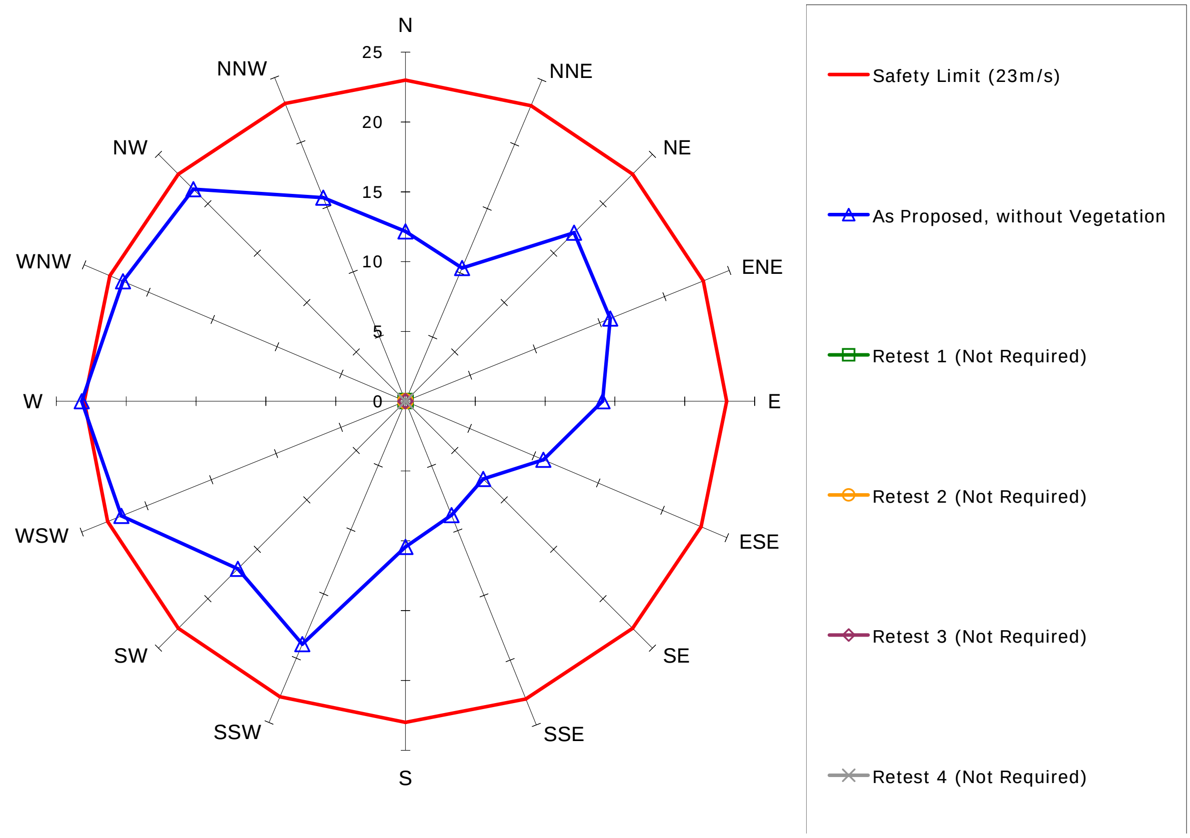


Measured Wind Speeds at Point 30

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

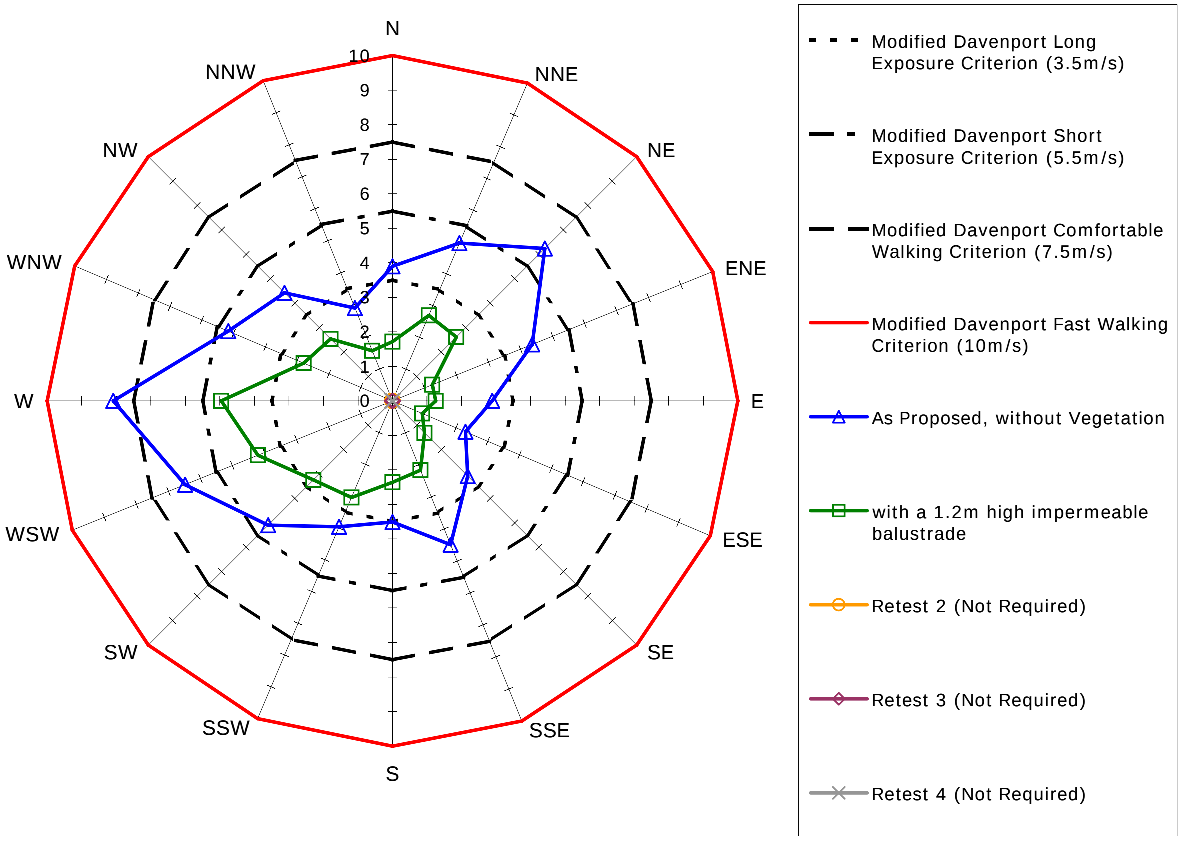


Annual Maximum Gust Wind Speeds (m/s)

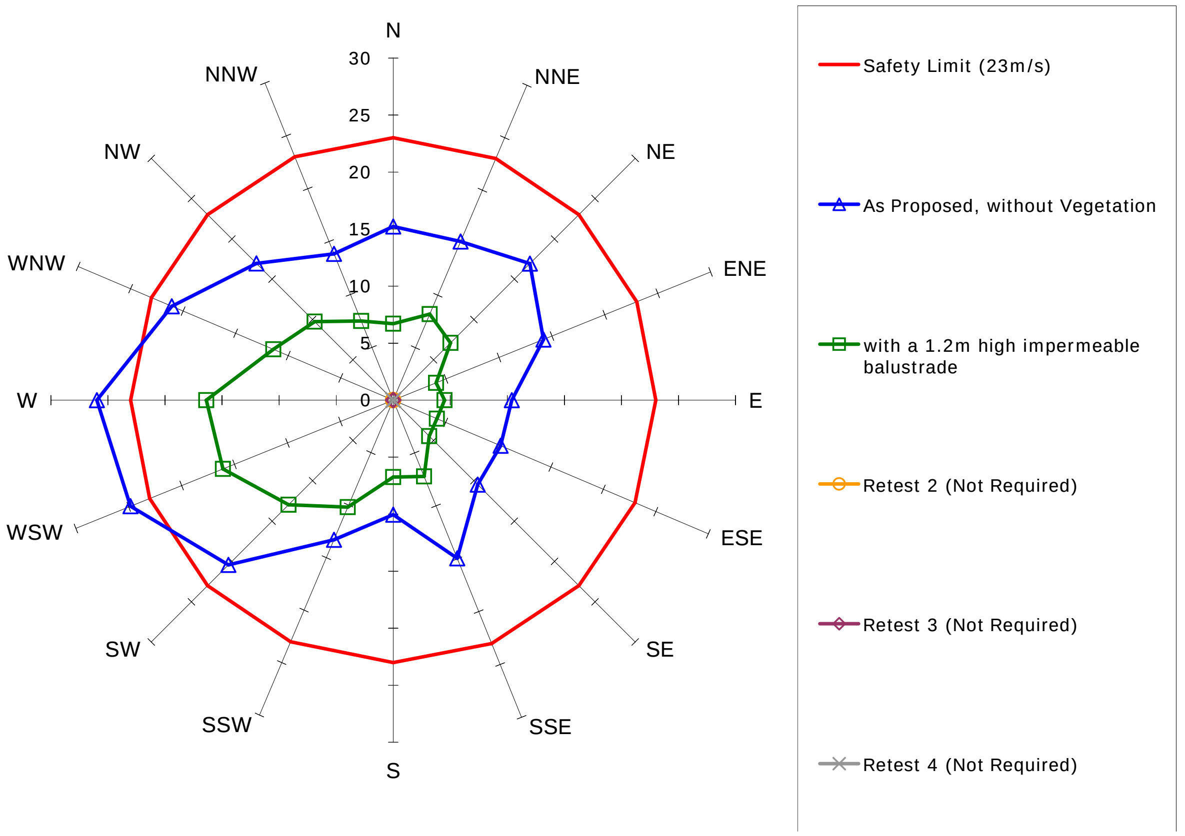


Measured Wind Speeds at Point 31

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

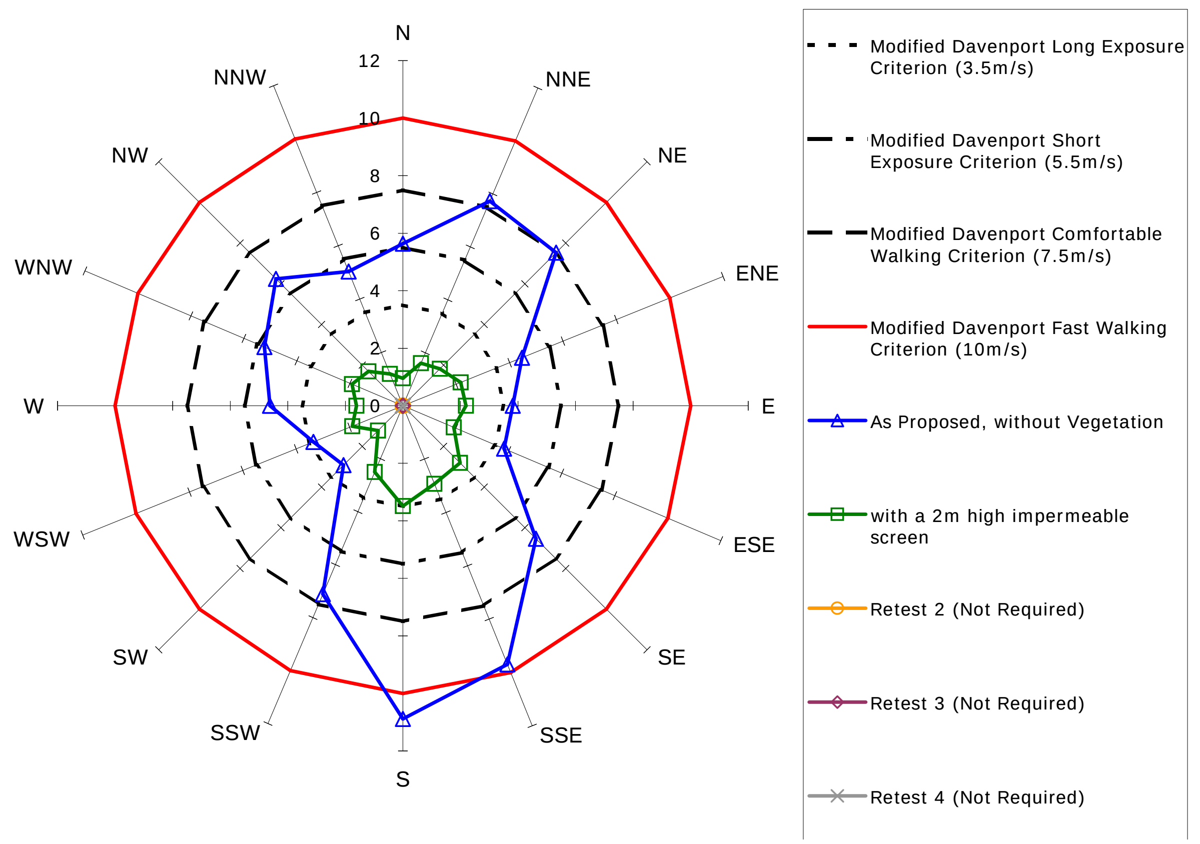


Annual Maximum Gust Wind Speeds (m/s)

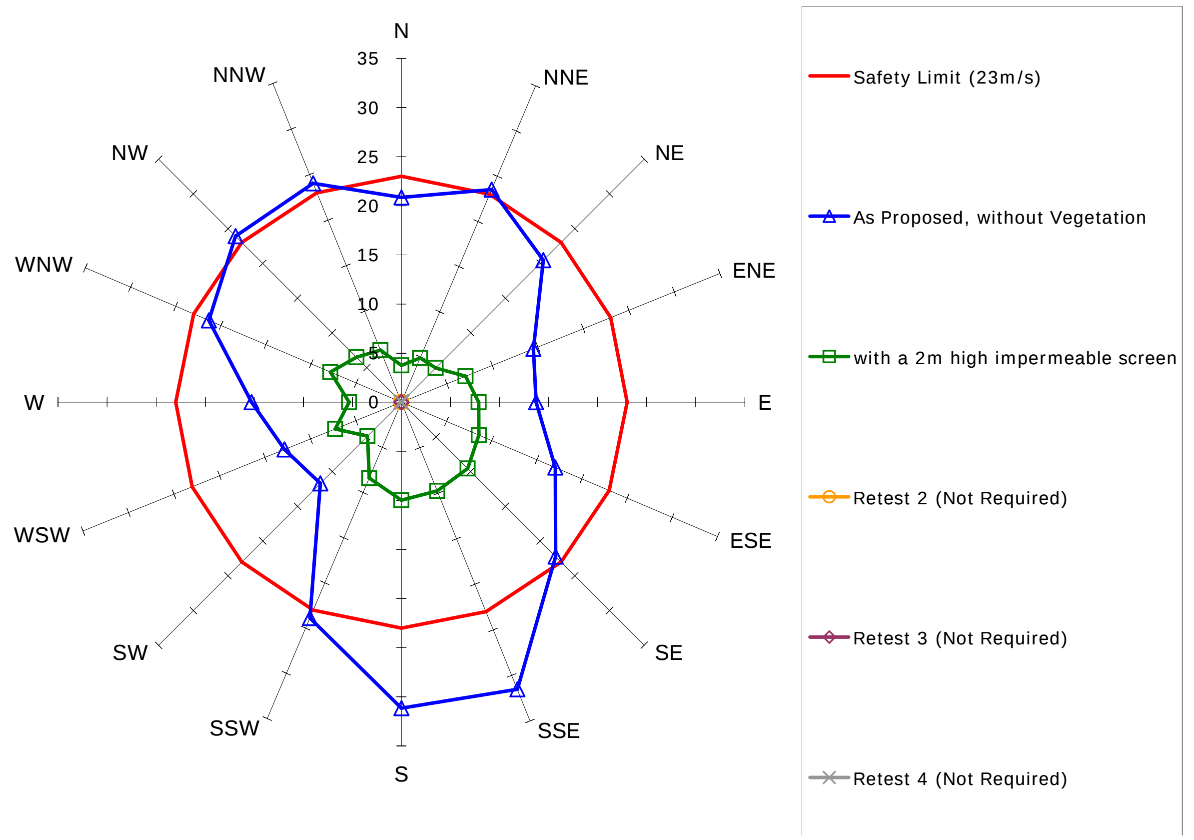


Measured Wind Speeds at Point 32

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

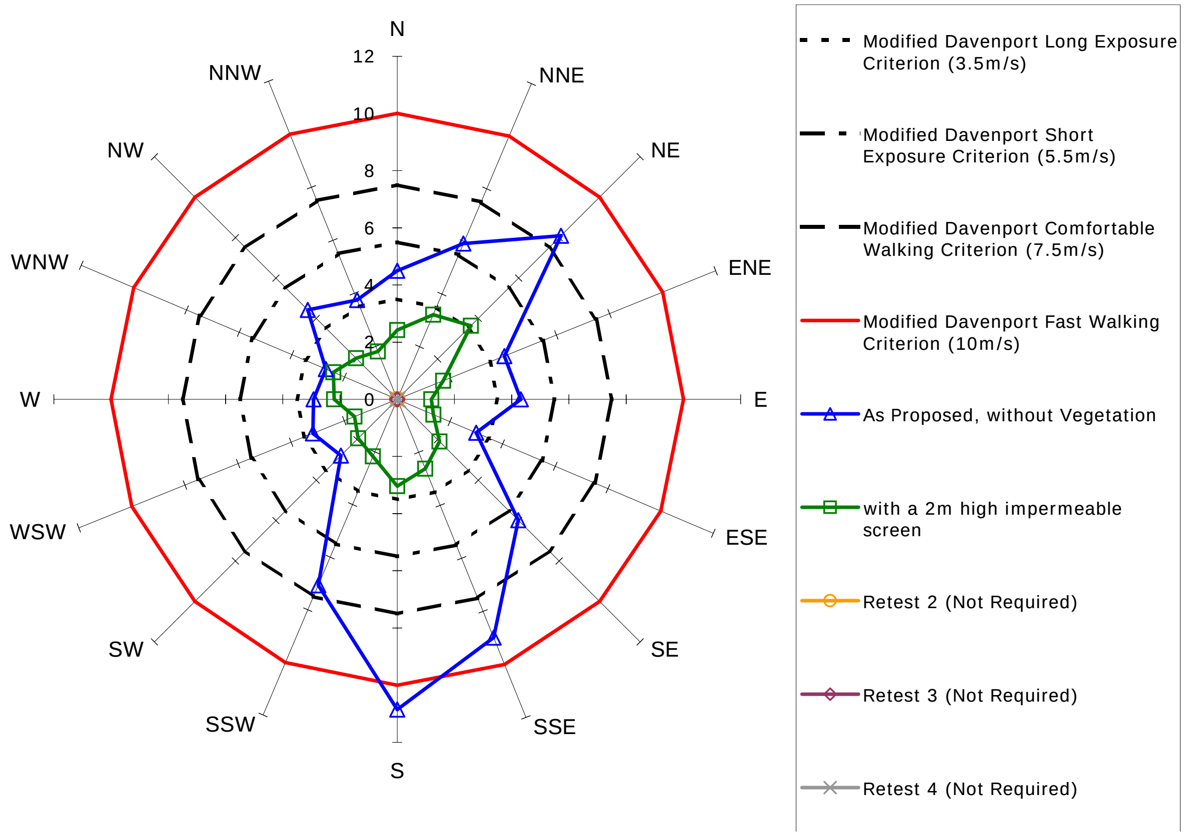


Annual Maximum Gust Wind Speeds (m/s)

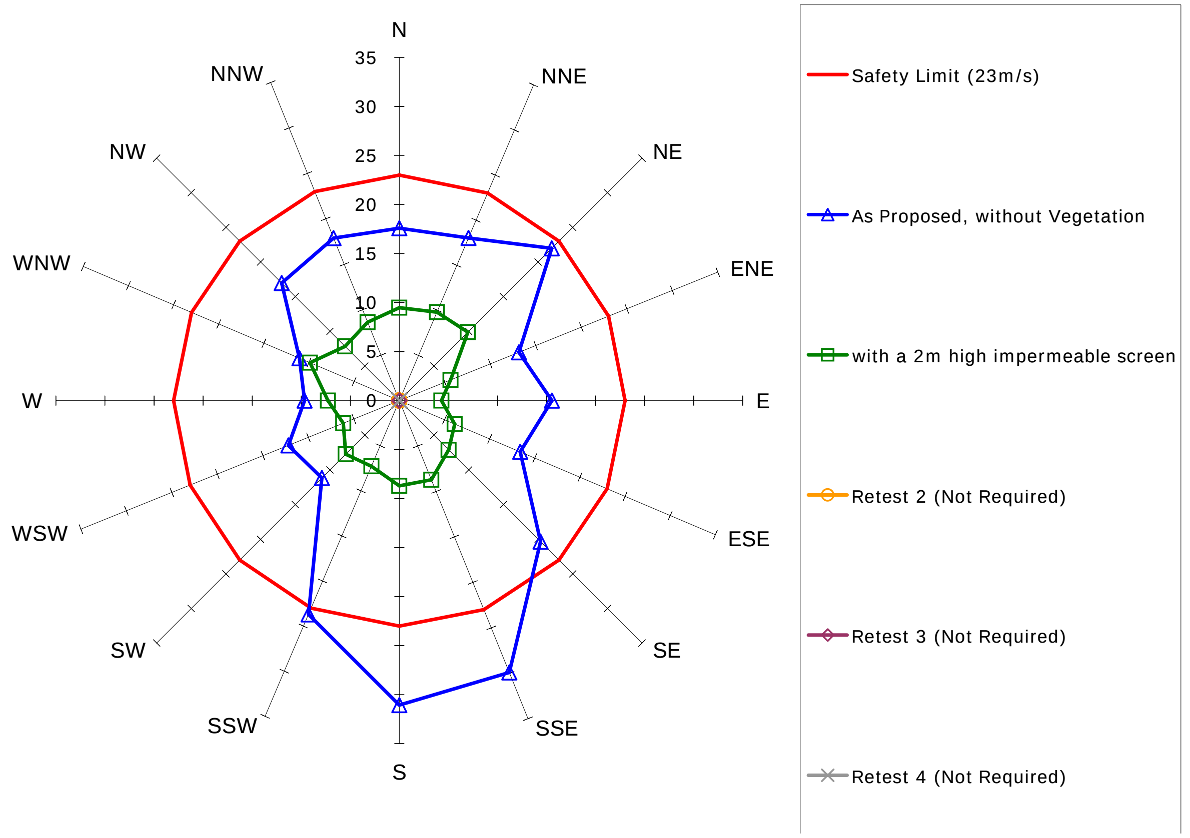


Measured Wind Speeds at Point 33

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

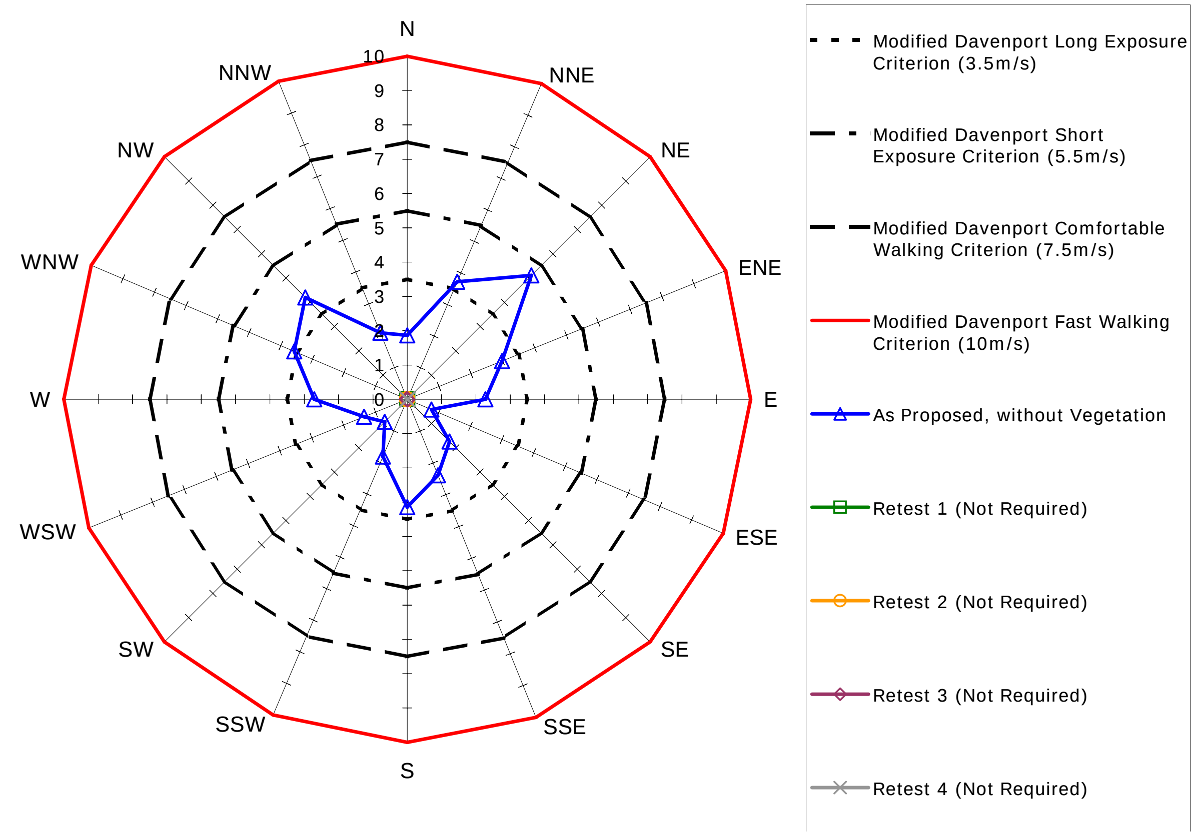


Annual Maximum Gust Wind Speeds (m/s)

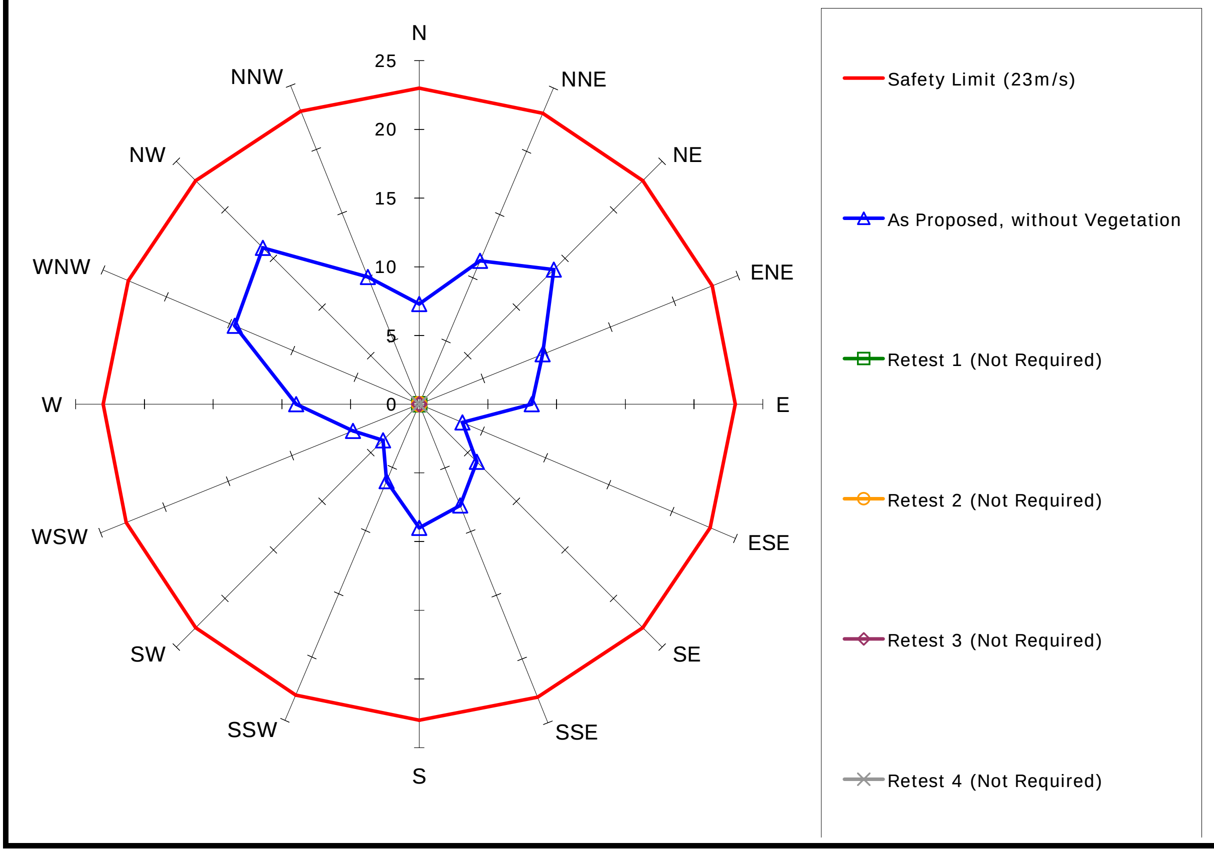


Measured Wind Speeds at Point 34

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

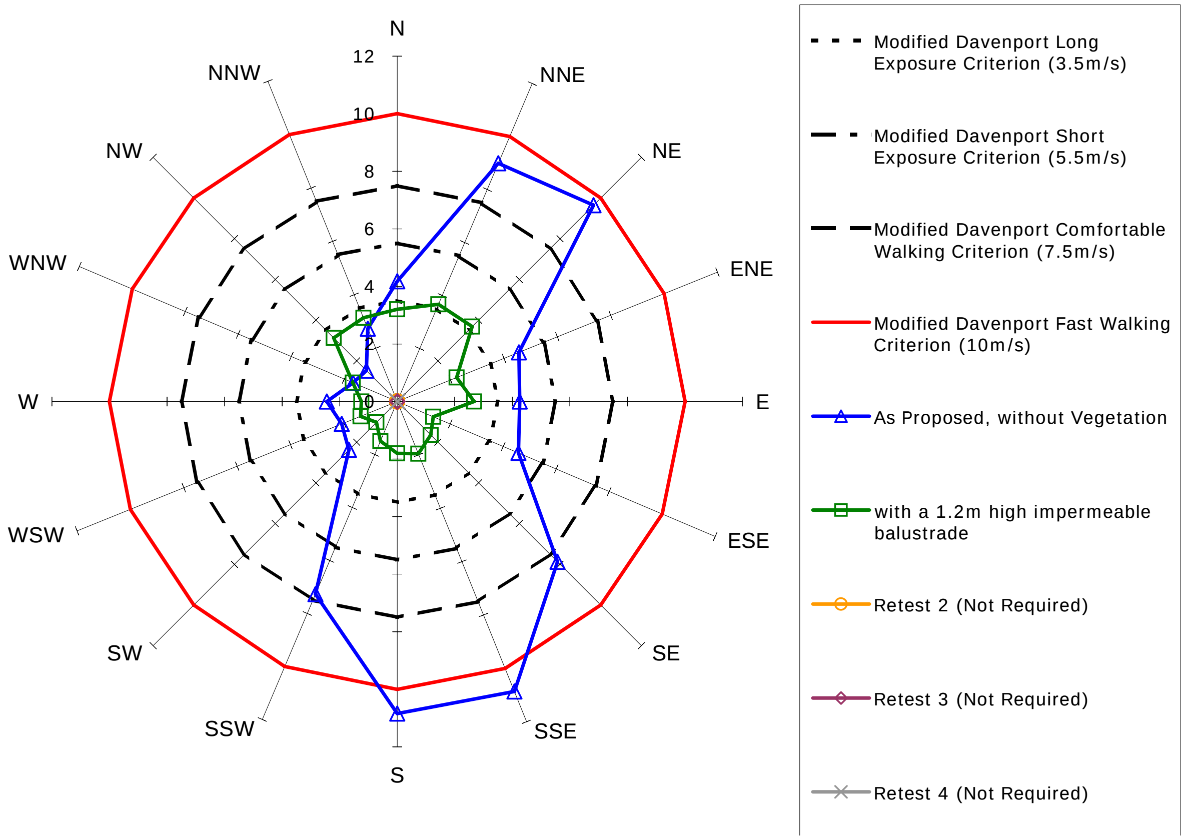


Annual Maximum Gust Wind Speeds (m/s)

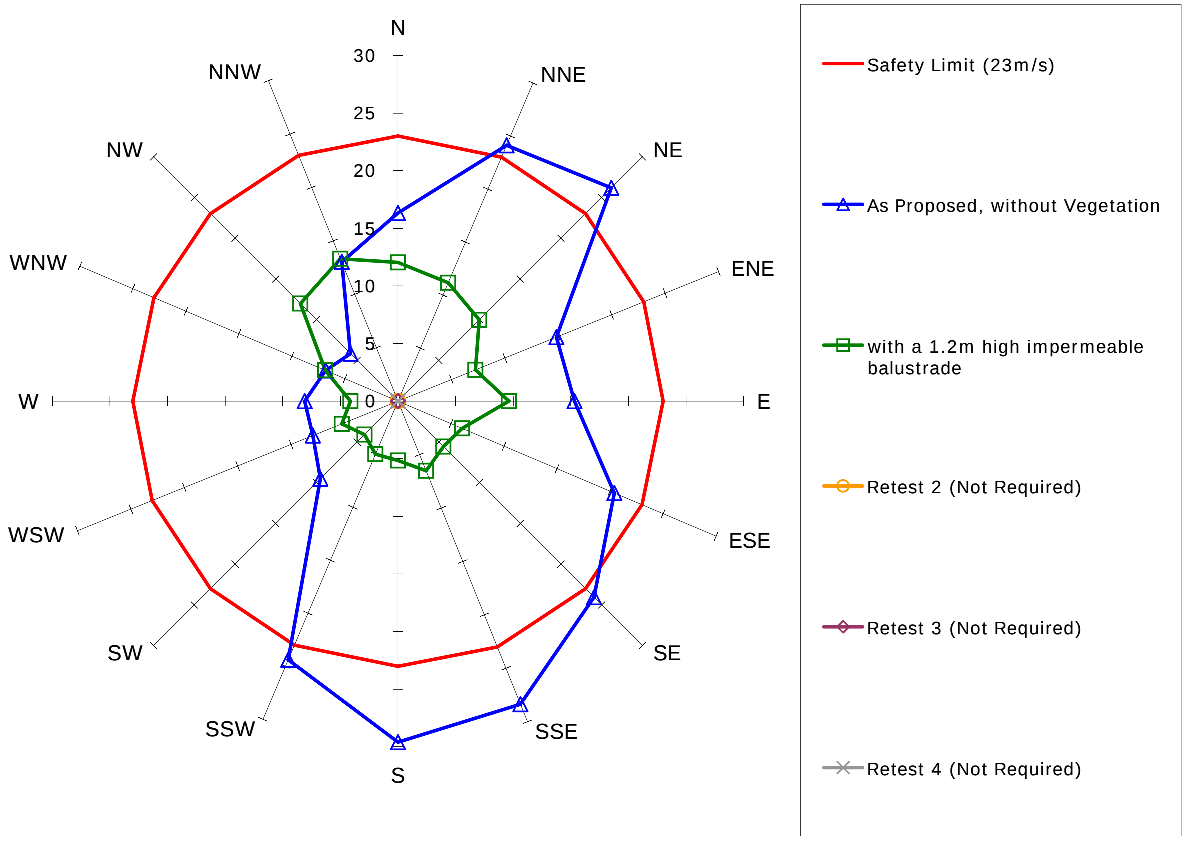


Measured Wind Speeds at Point 35

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

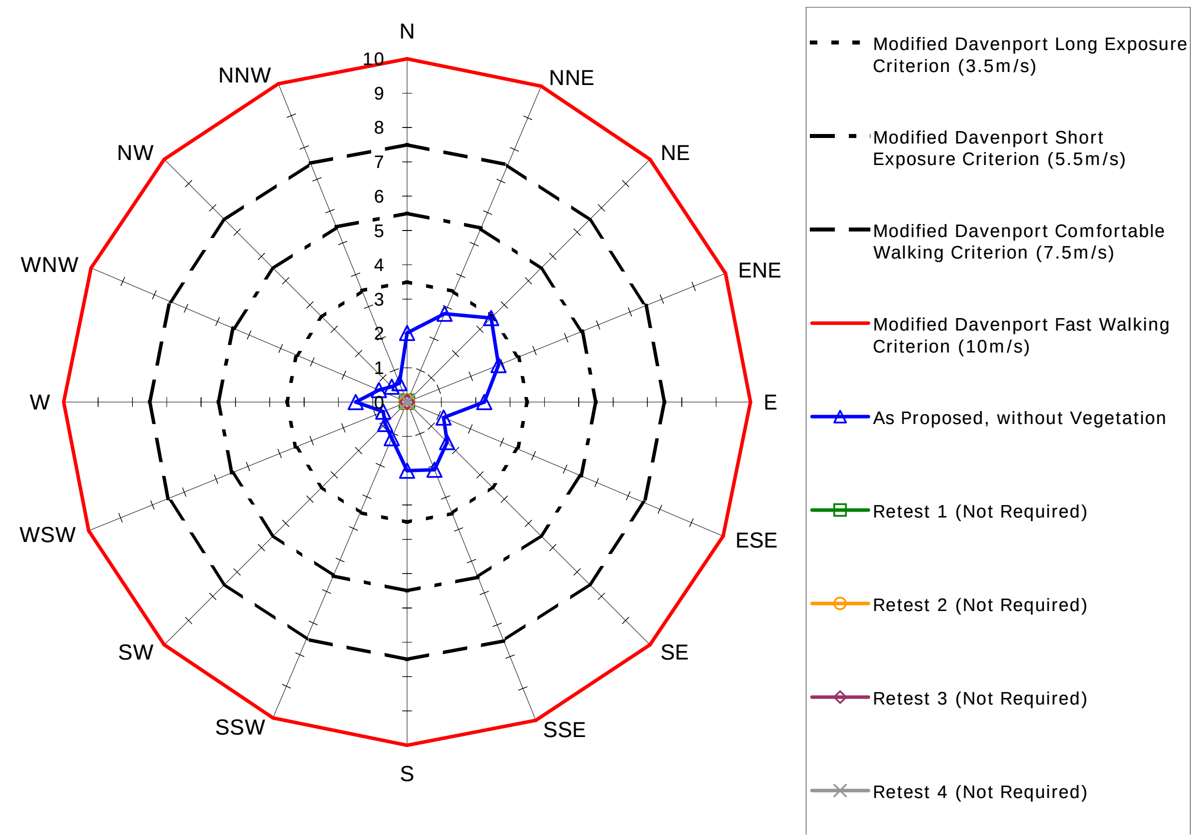


Annual Maximum Gust Wind Speeds (m/s)

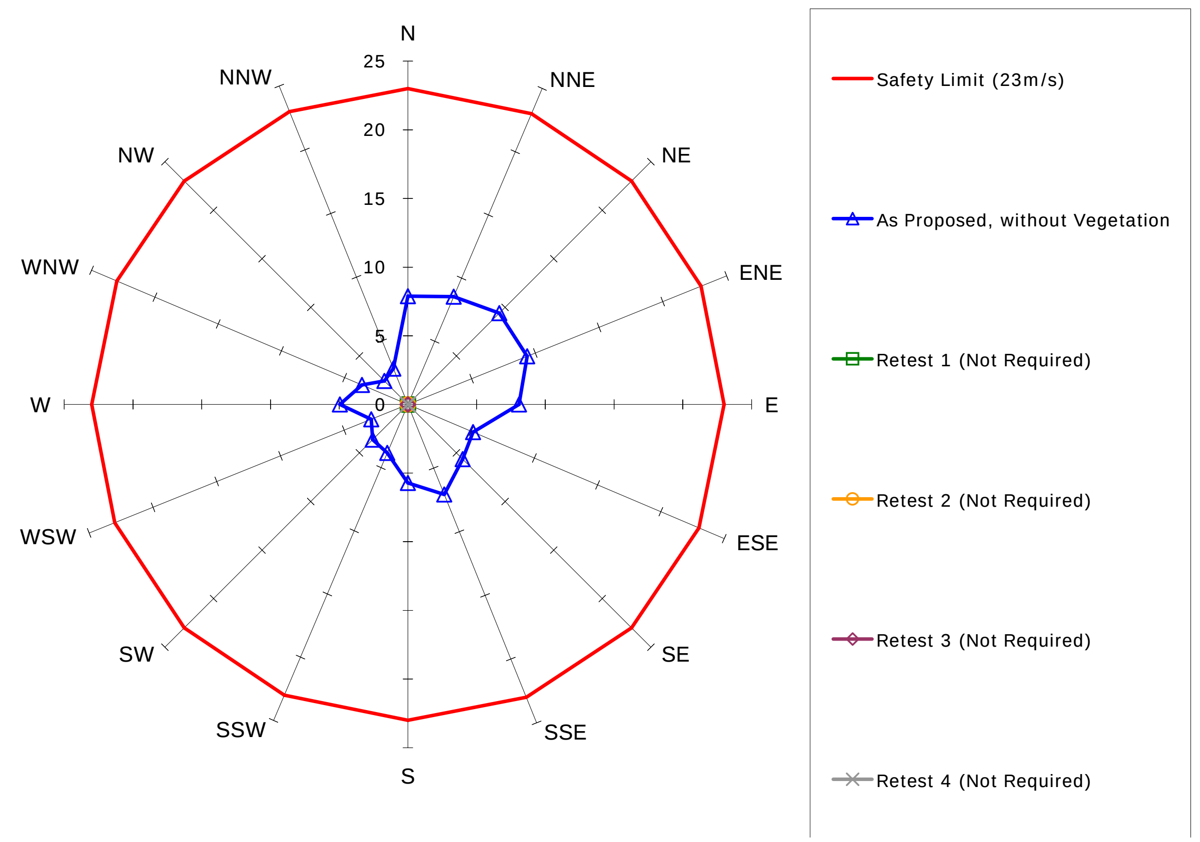


Measured Wind Speeds at Point 36

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

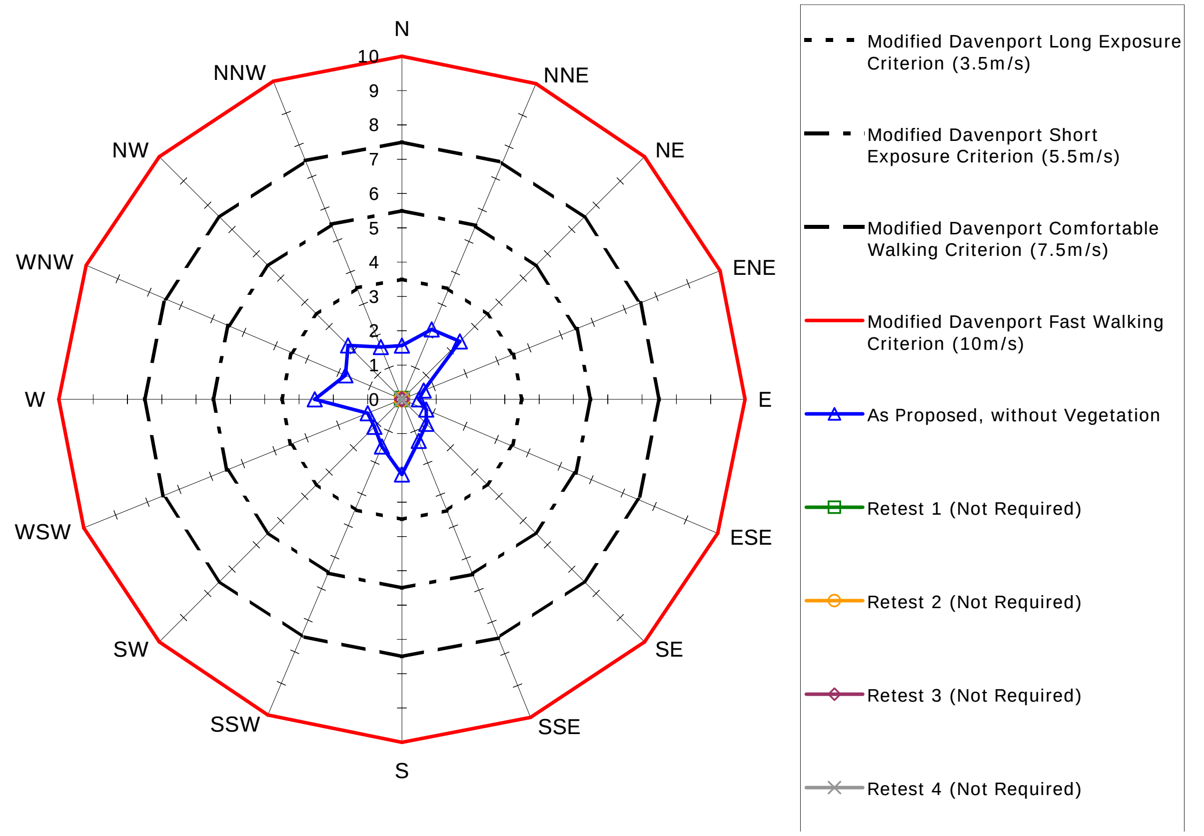


Annual Maximum Gust Wind Speeds (m/s)

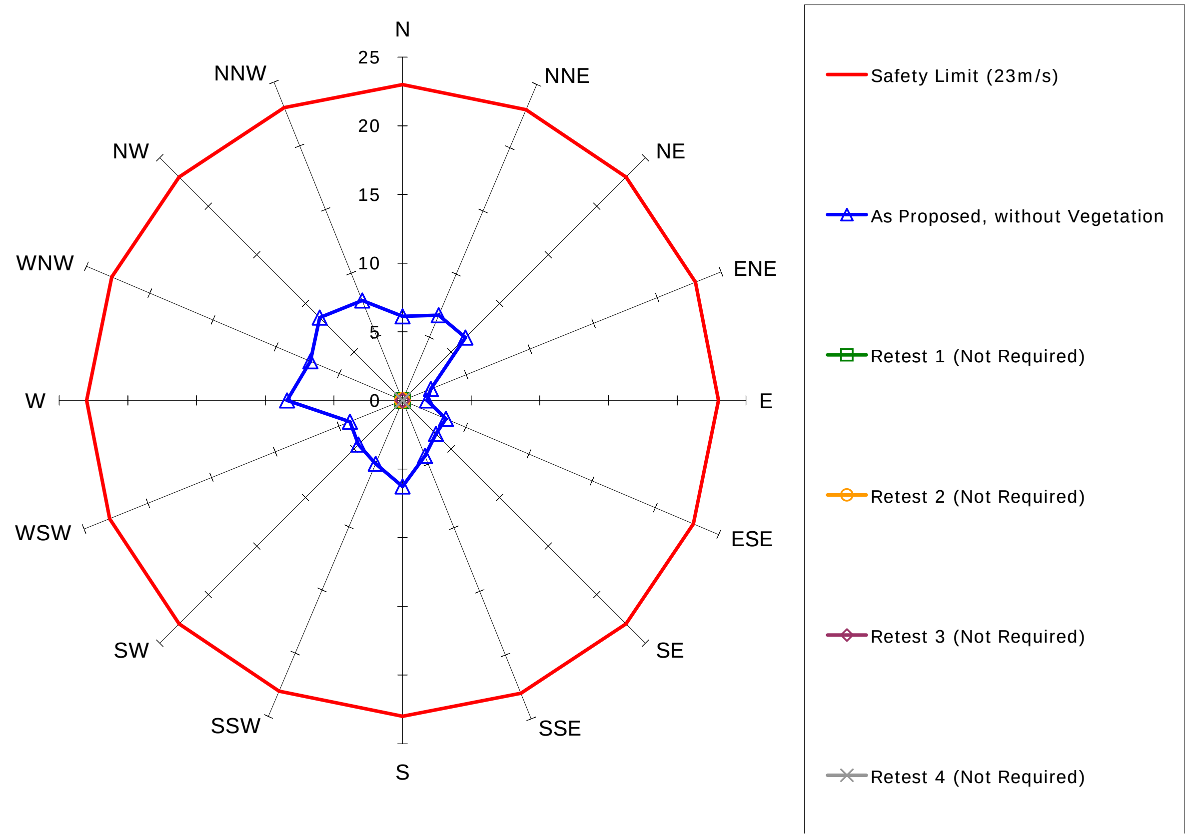


Measured Wind Speeds at Point 37

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

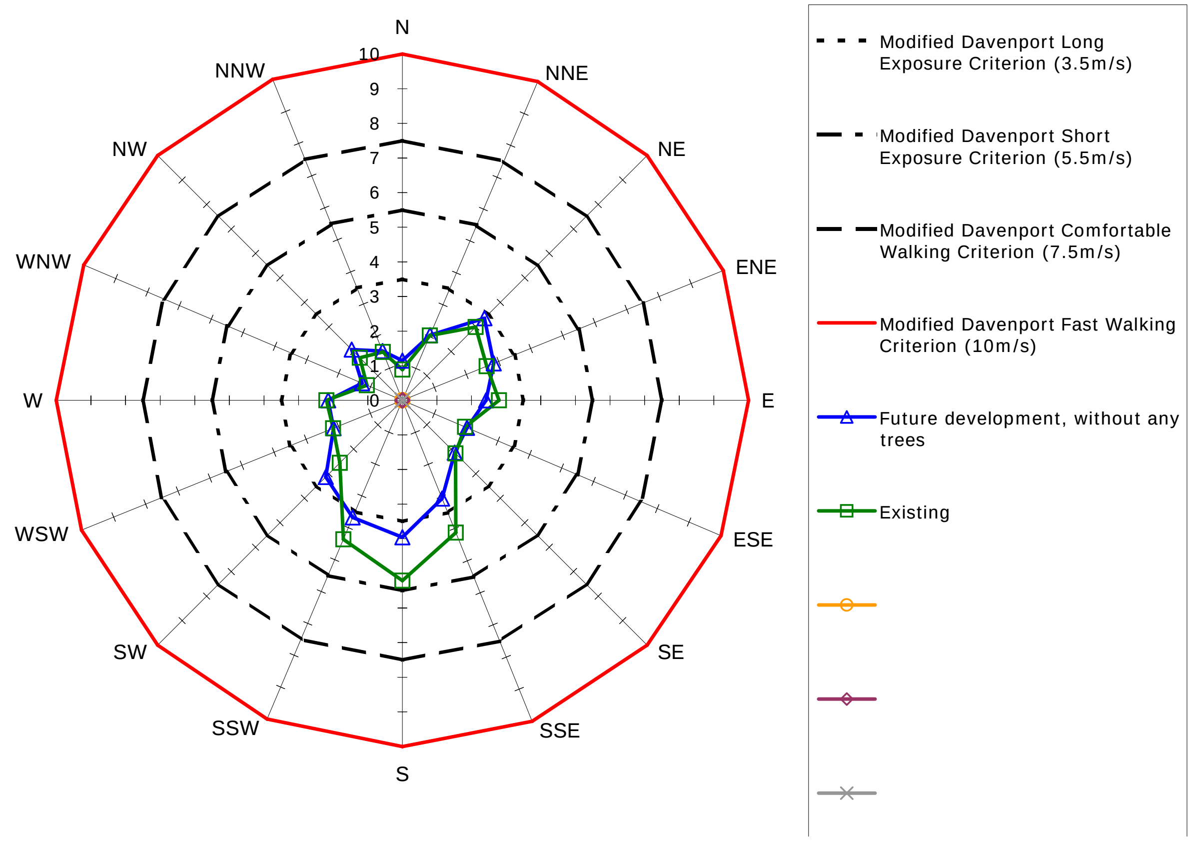


Annual Maximum Gust Wind Speeds (m/s)

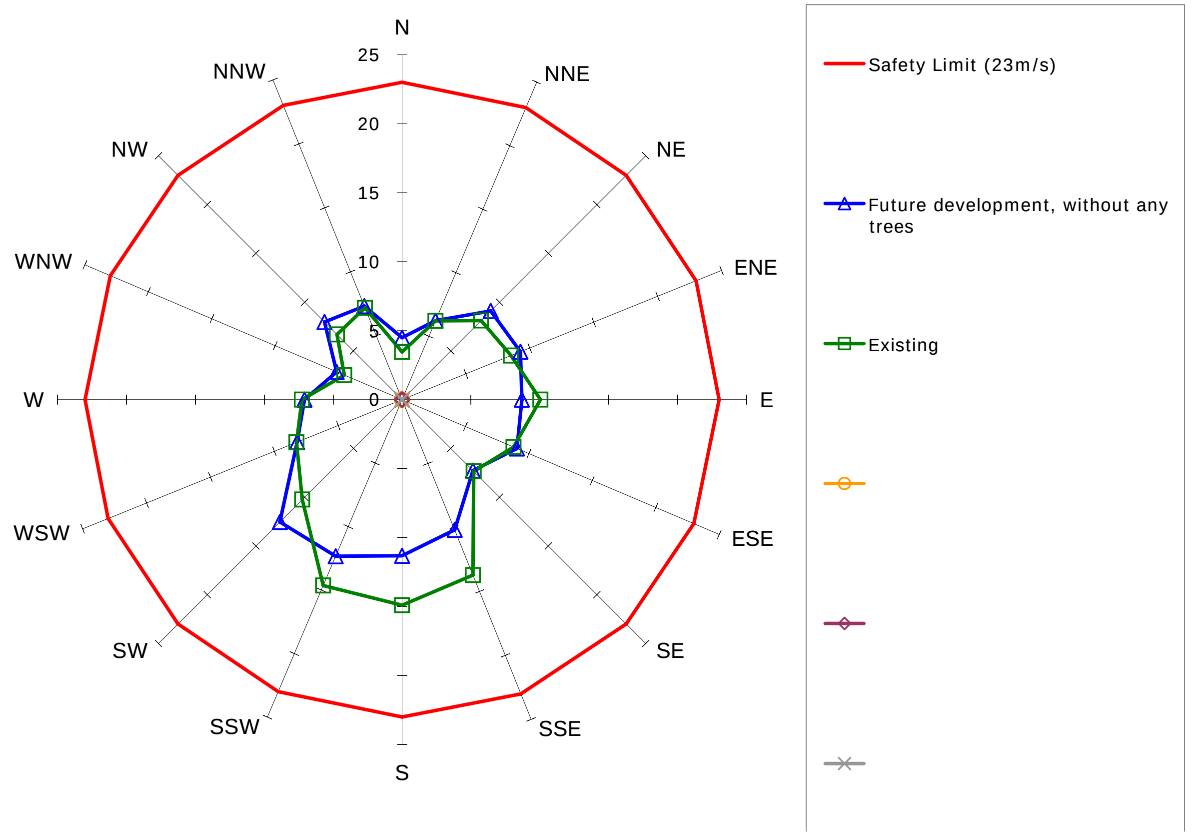


Measured Wind Speeds at Point A

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

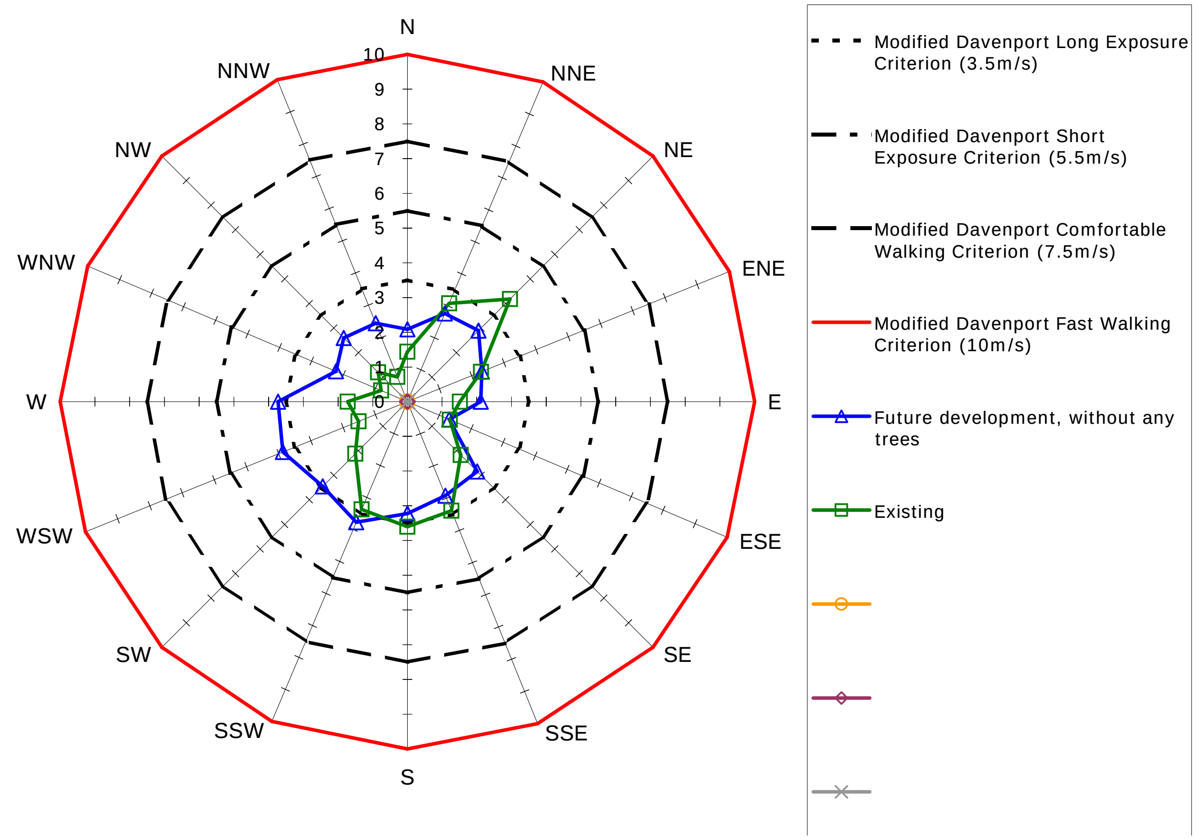


Annual Maximum Gust Wind Speeds (m/s)

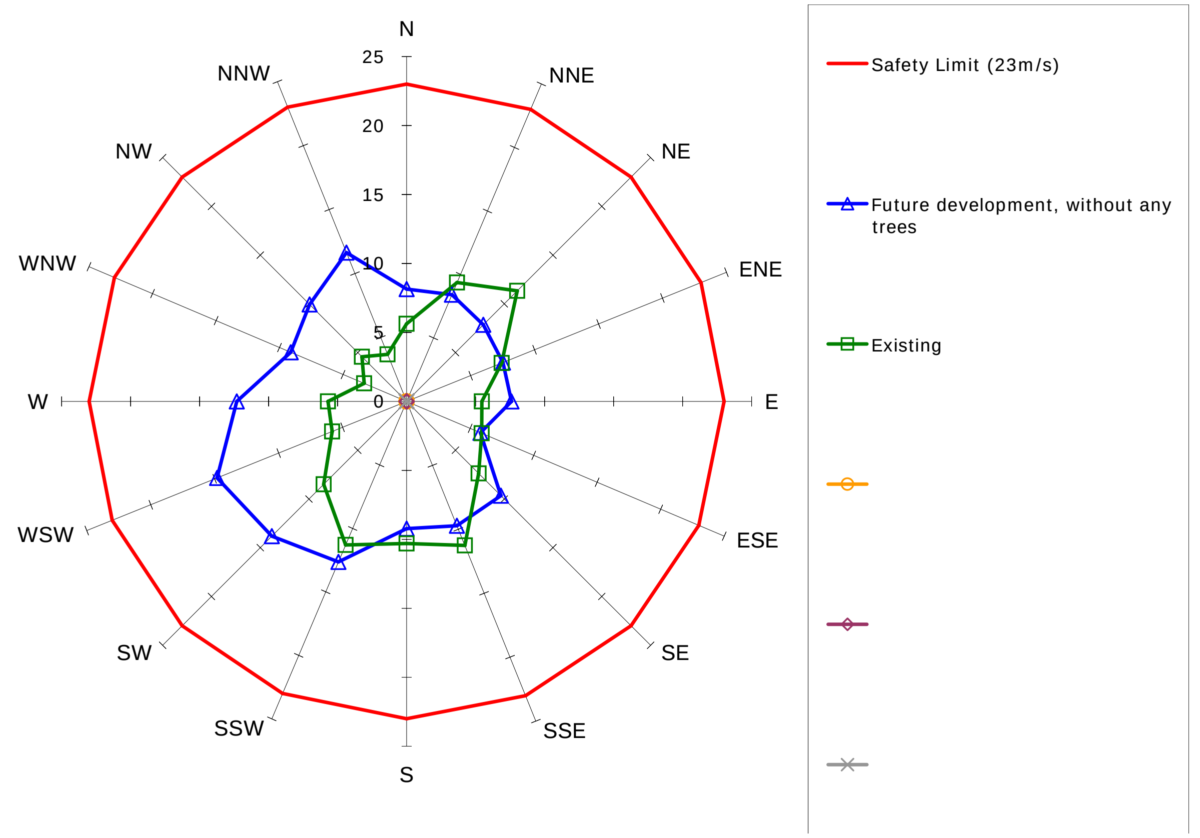


Measured Wind Speeds at Point B

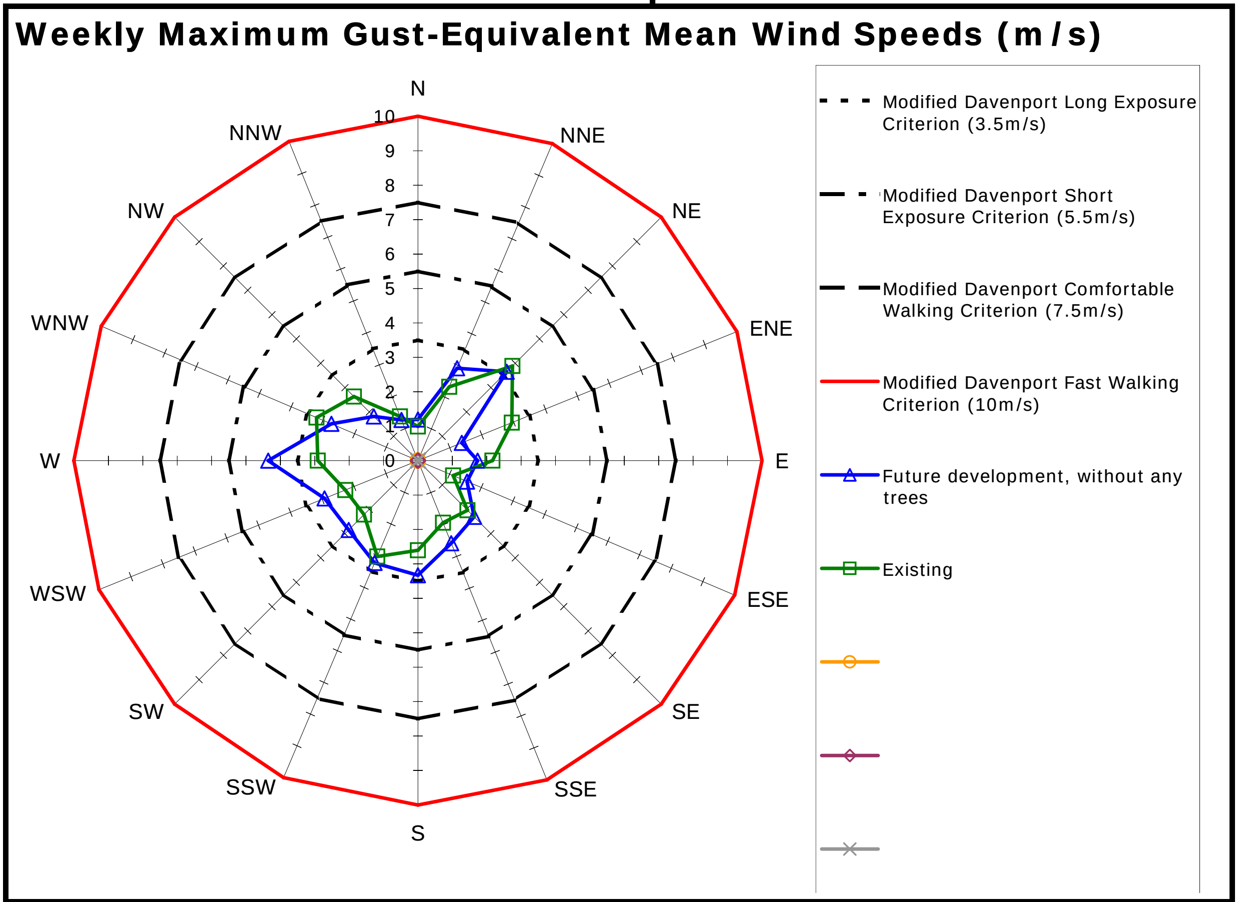
Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

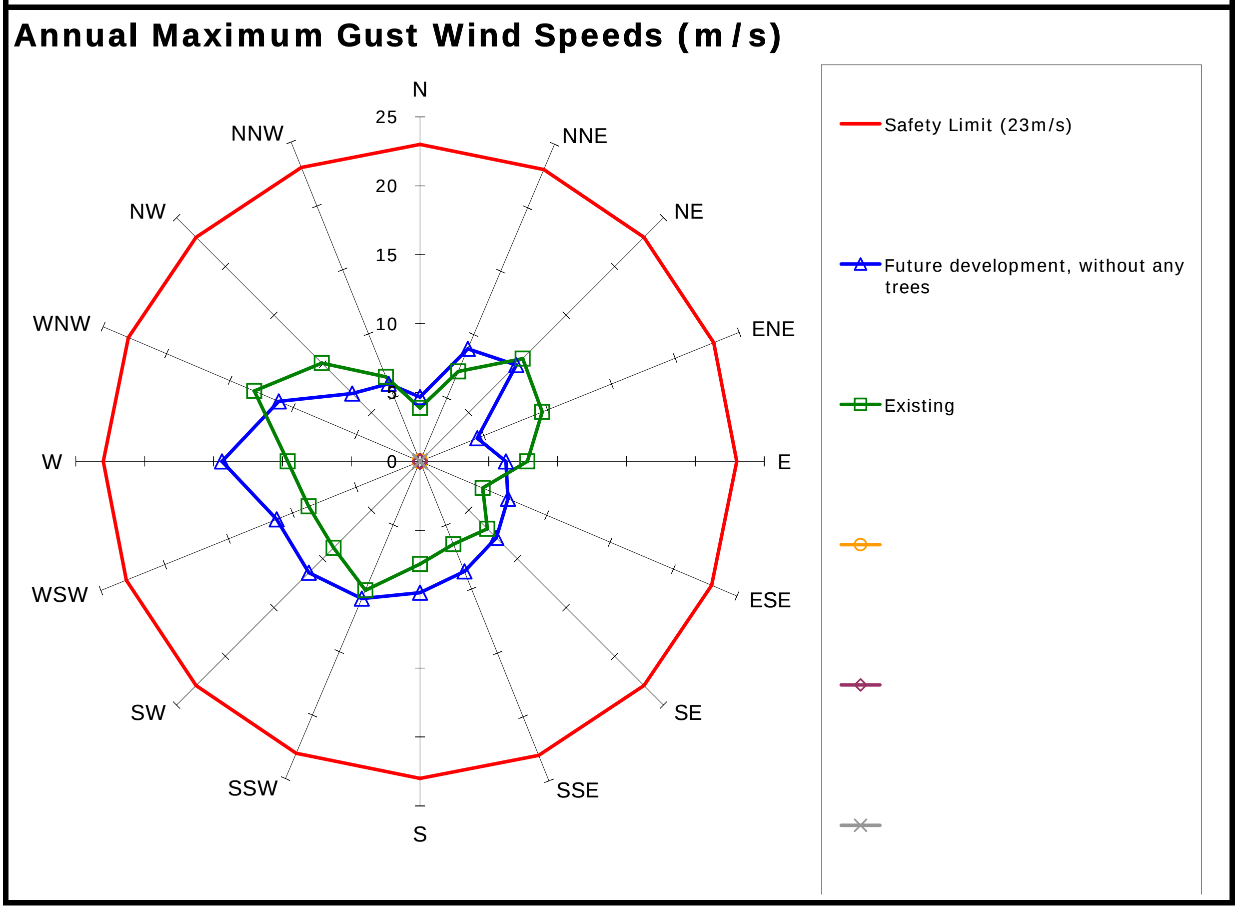


Annual Maximum Gust Wind Speeds (m/s)



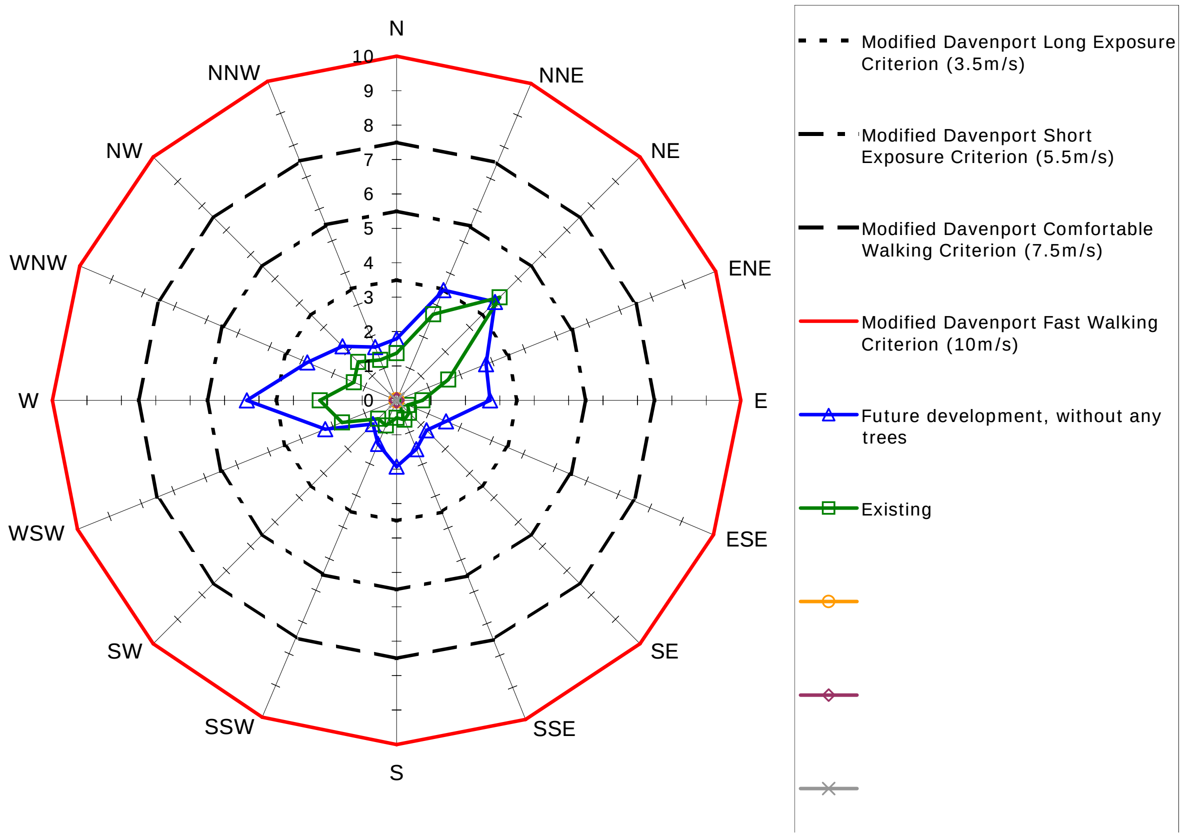
Measured Wind Speeds at Point C



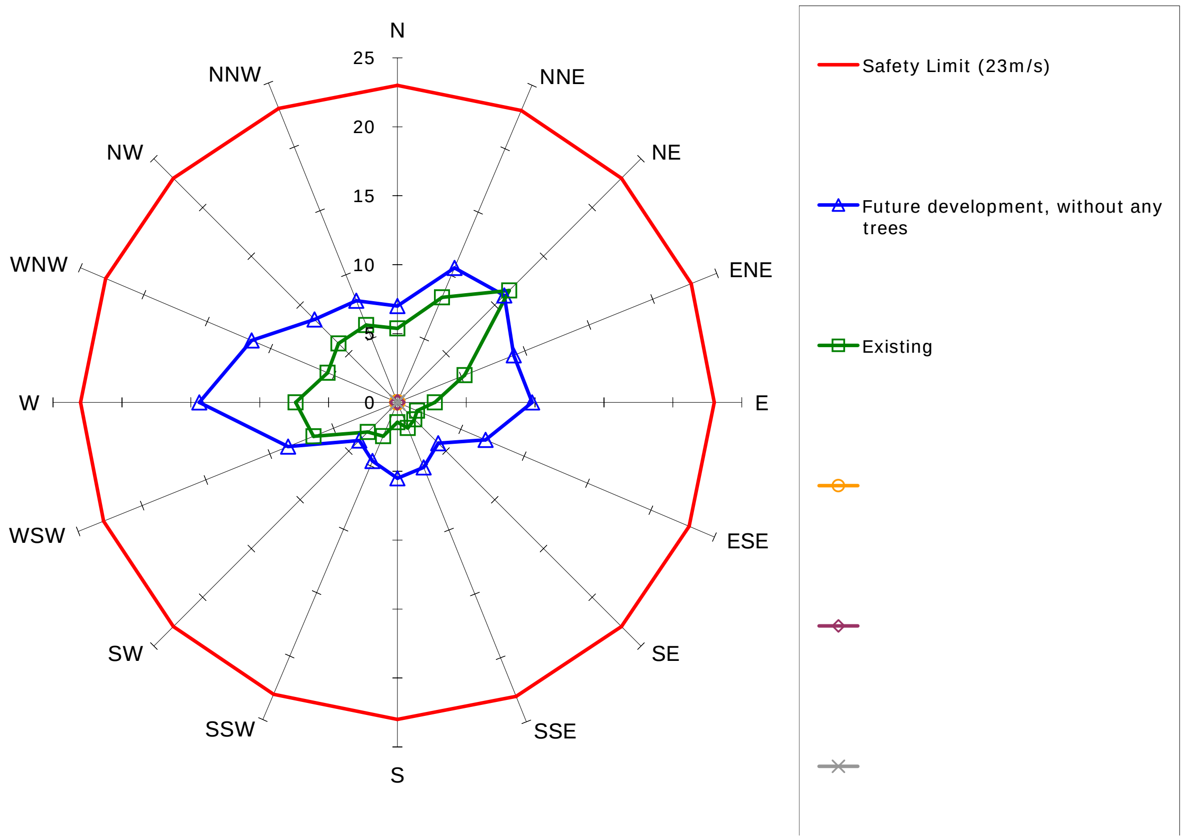


Measured Wind Speeds at Point D

Weekly Maximum Gust-Equivalent Mean Wind Speeds (m/s)

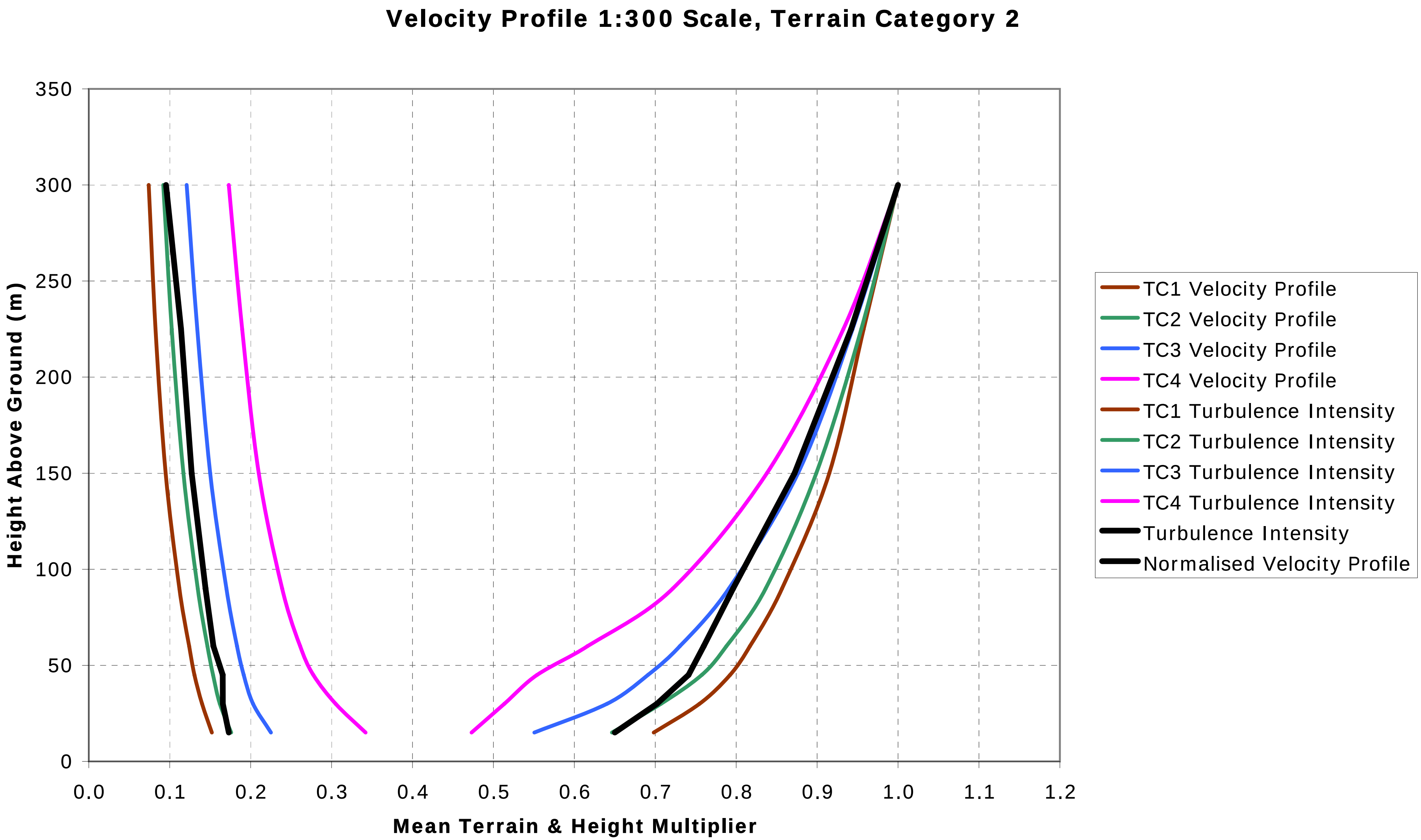


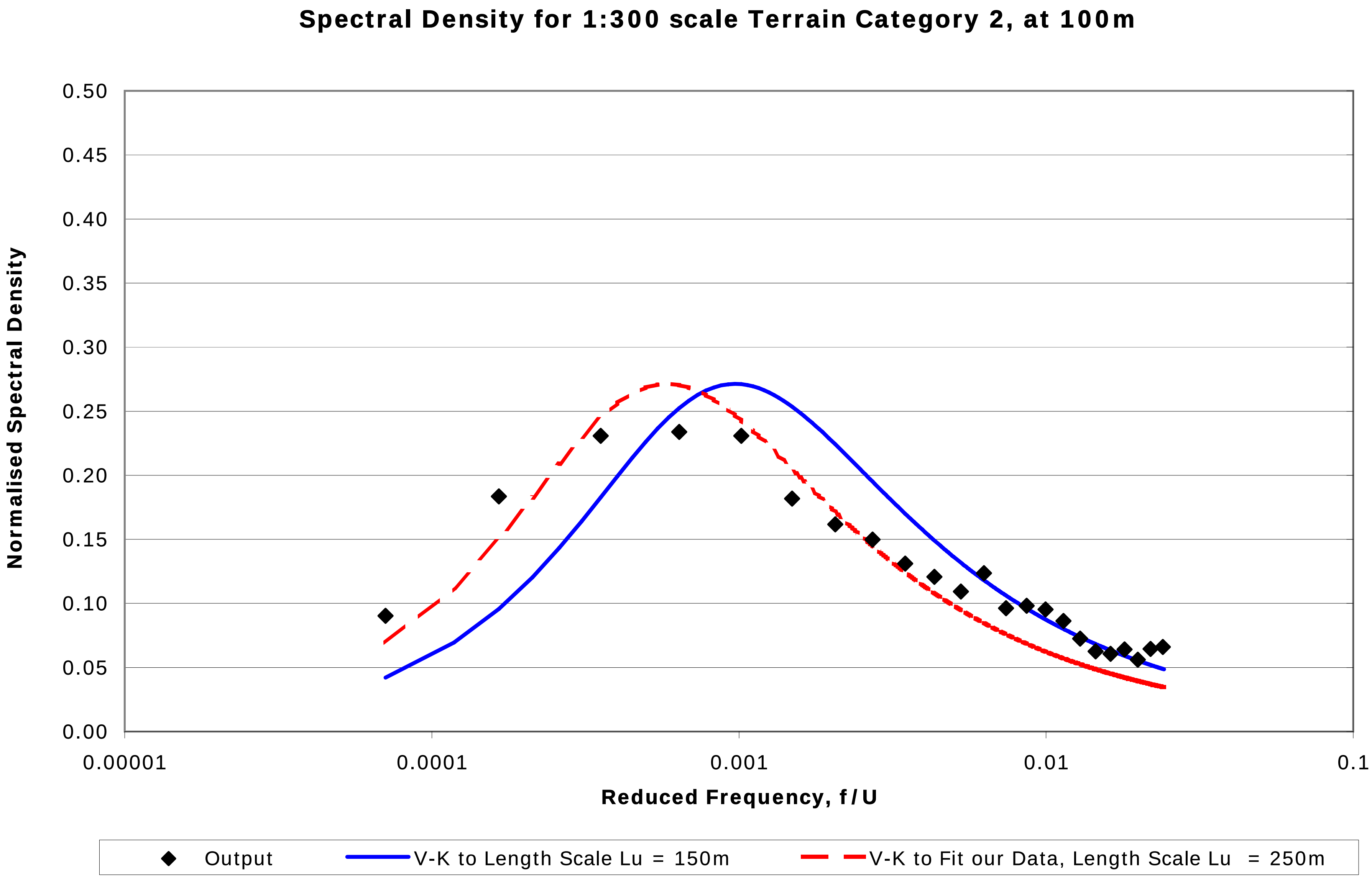
Annual Maximum Gust Wind Speeds (m/s)

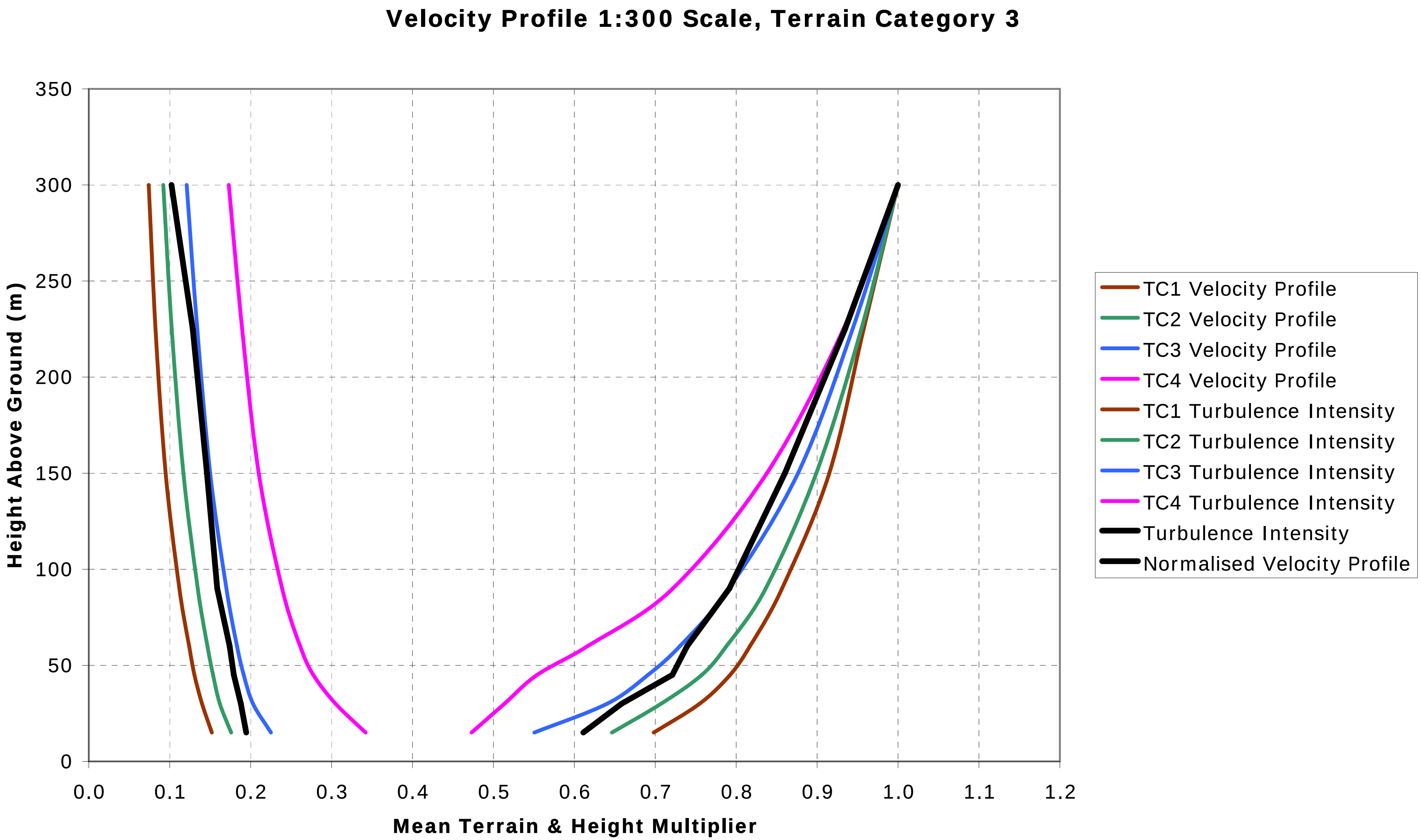


Appendix B

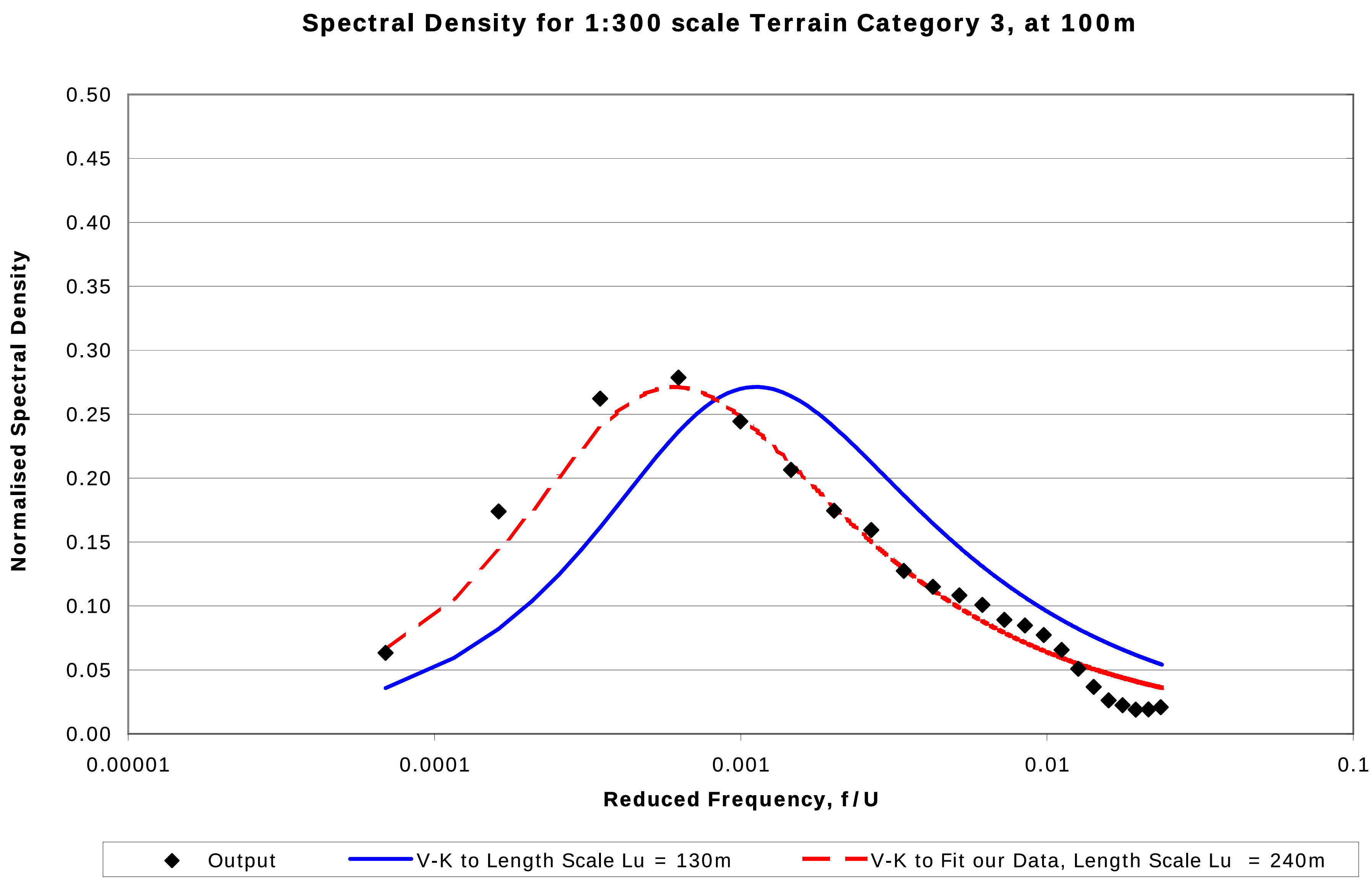
Wind Tunnel Boundary Layer Profile

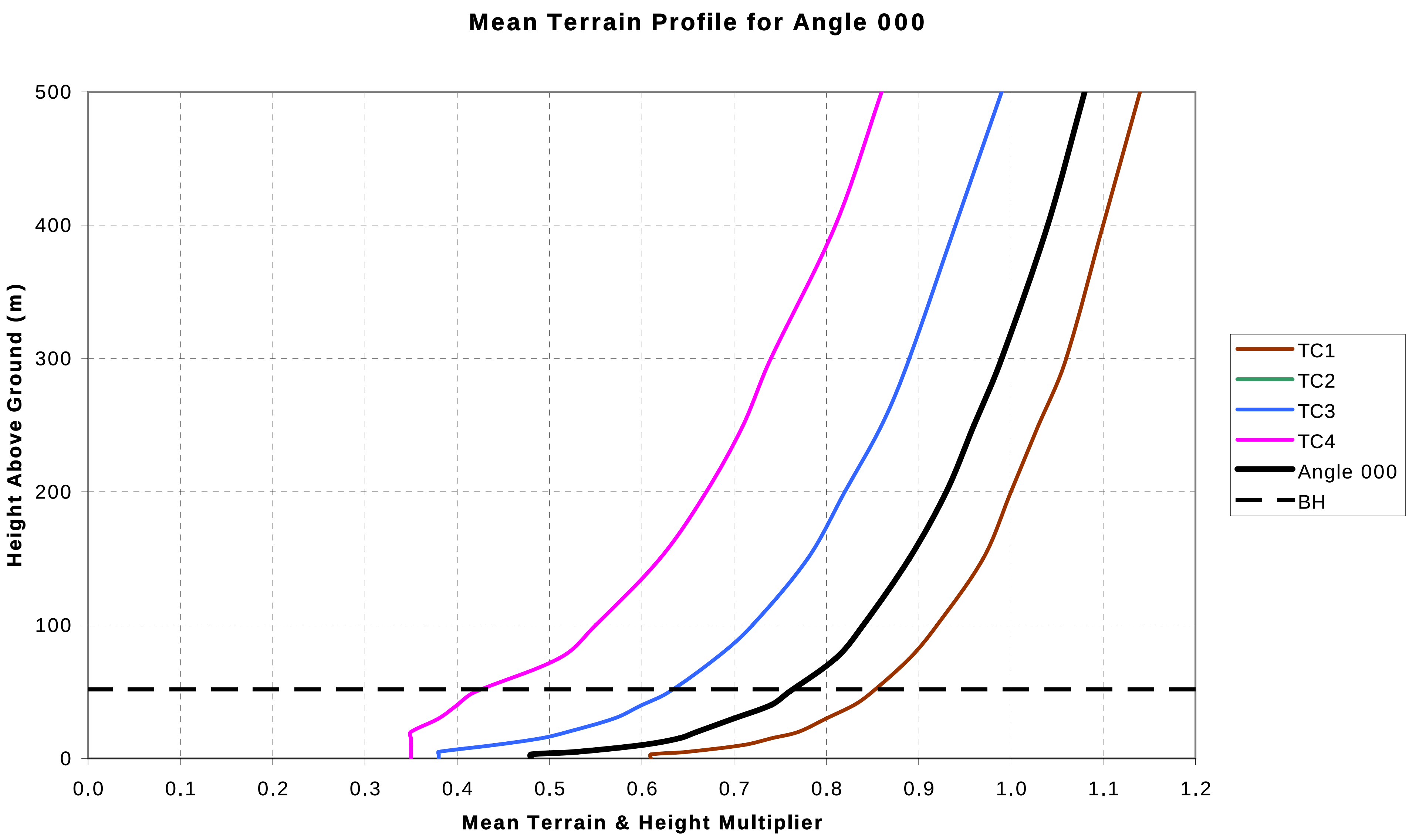

Velocity Profile 1:300 Scale, Terrain Category 2
Height Above Ground (m)
0
50
100
150
200
250
300
350
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1 Velocity Profile
TC2 Velocity Profile
TC3 Velocity Profile
TC4 Velocity Profile
TC1 Turbulence Intensity
TC2 Turbulence Intensity
TC3 Turbulence Intensity
TC4 Turbulence Intensity
Turbulence Intensity
Normalised Velocity Profile


Spectral Density for 1:300 scale Terrain Category 2, at 100m
Normalised Spectral Density
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.00001
0.0001
0.001
0.01
0.1
Reduced Frequency, f/U
Output
V-K to Length Scale Lu = 150m
V-K to Fit our Data, Length Scale Lu = 250m

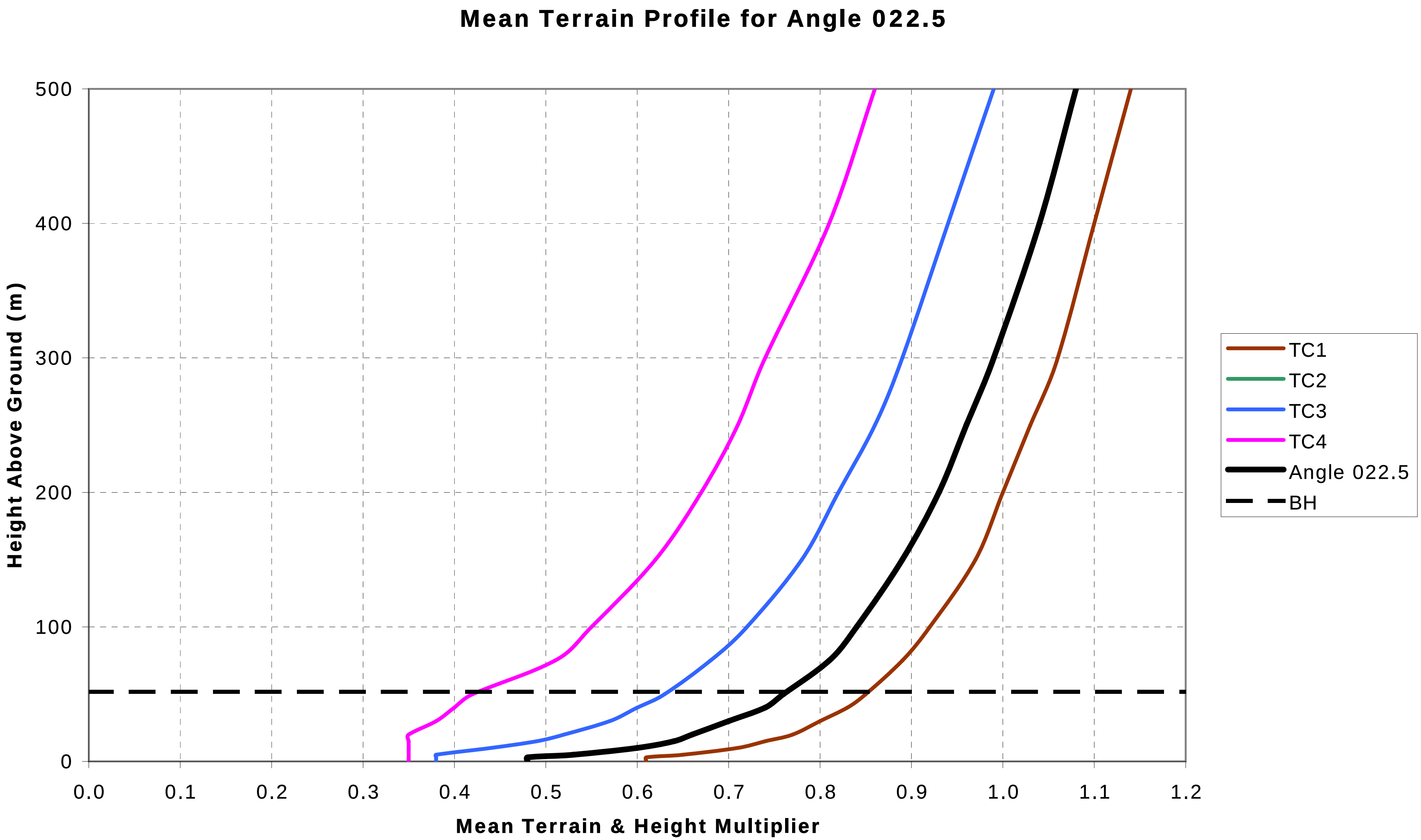


Velocity Profile 1:300 Scale, Terrain Category 3
Height Above Ground (m)
350
300
250
200
150
100
50
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1 Velocity Profile
TC2 Velocity Profile
TC3 Velocity Profile
TC4 Velocity Profile
TC1 Turbulence Intensity
TC2 Turbulence Intensity
TC3 Turbulence Intensity
TC4 Turbulence Intensity
Turbulence Intensity
Normalised Velocity Profile

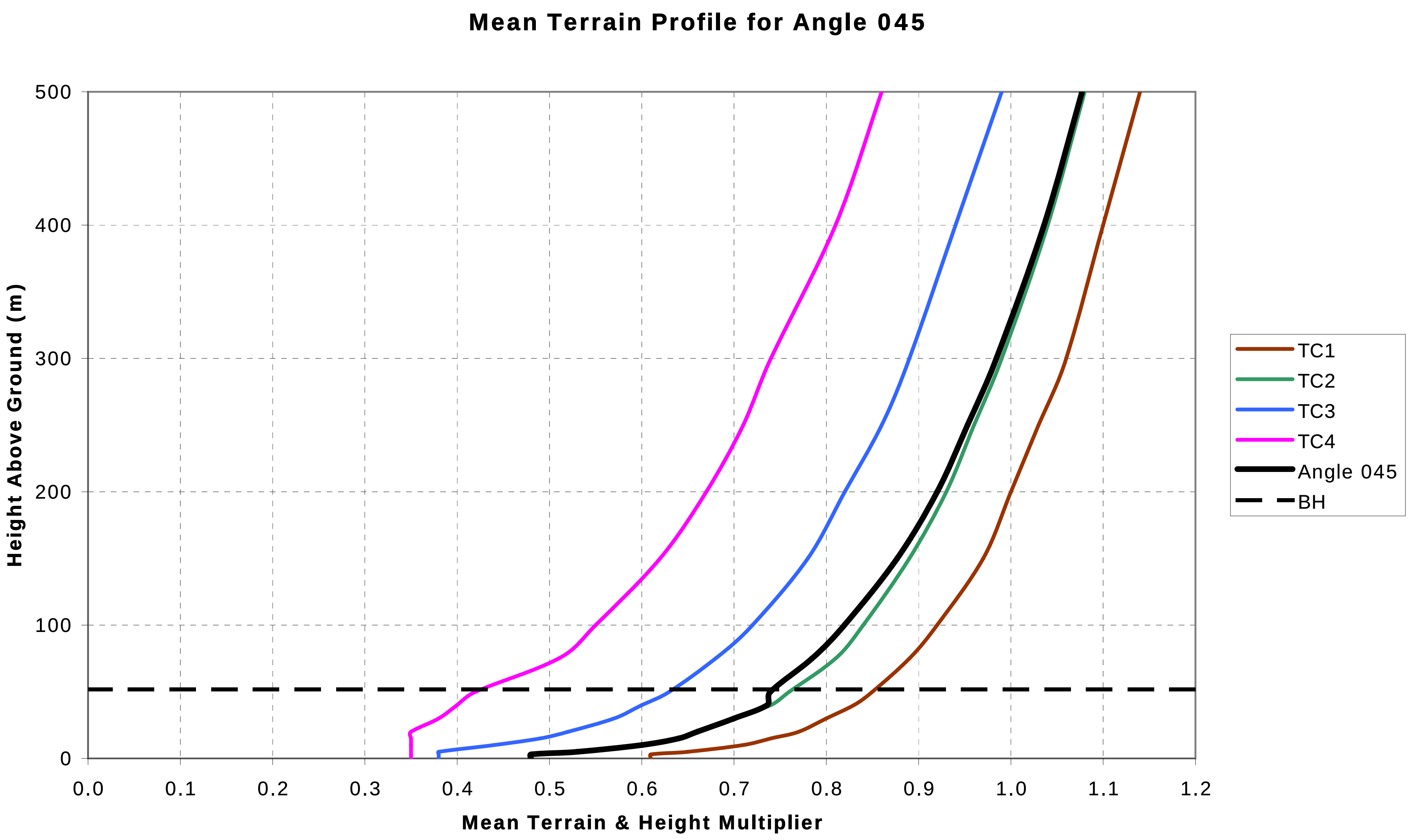

Spectral Density for 1:300 scale Terrain Category 3, at 100m
Normalised Spectral Density
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.00001
0.0001
0.001
0.01
0.1
Reduced Frequency, f/U
Output
V-K to Length Scale Lu = 130m
V-K to Fit our Data, Length Scale Lu = 240m



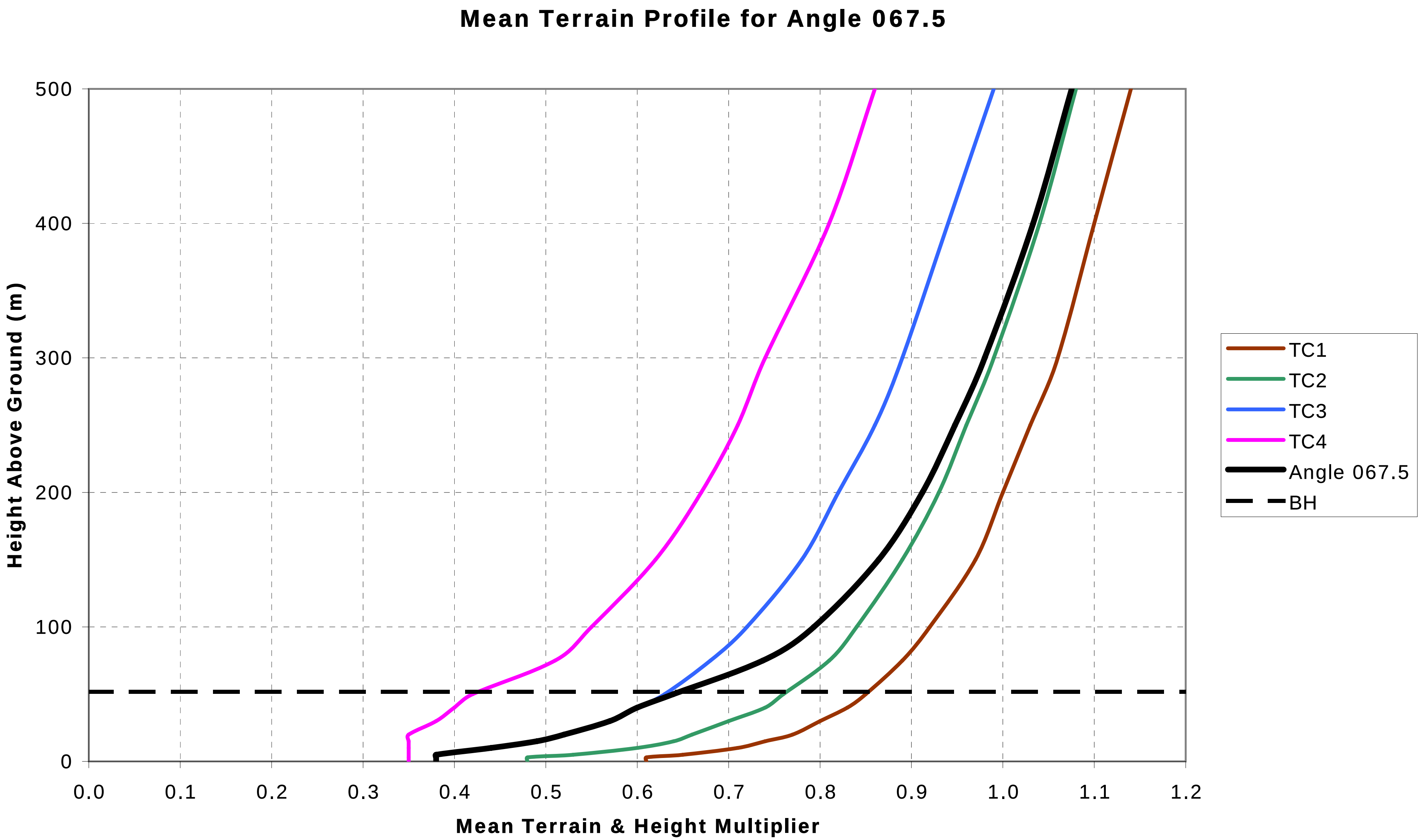
Mean Terrain Profile for Angle 000
Height Above Ground (m)
0
100
200
300
400
500
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 000
BH



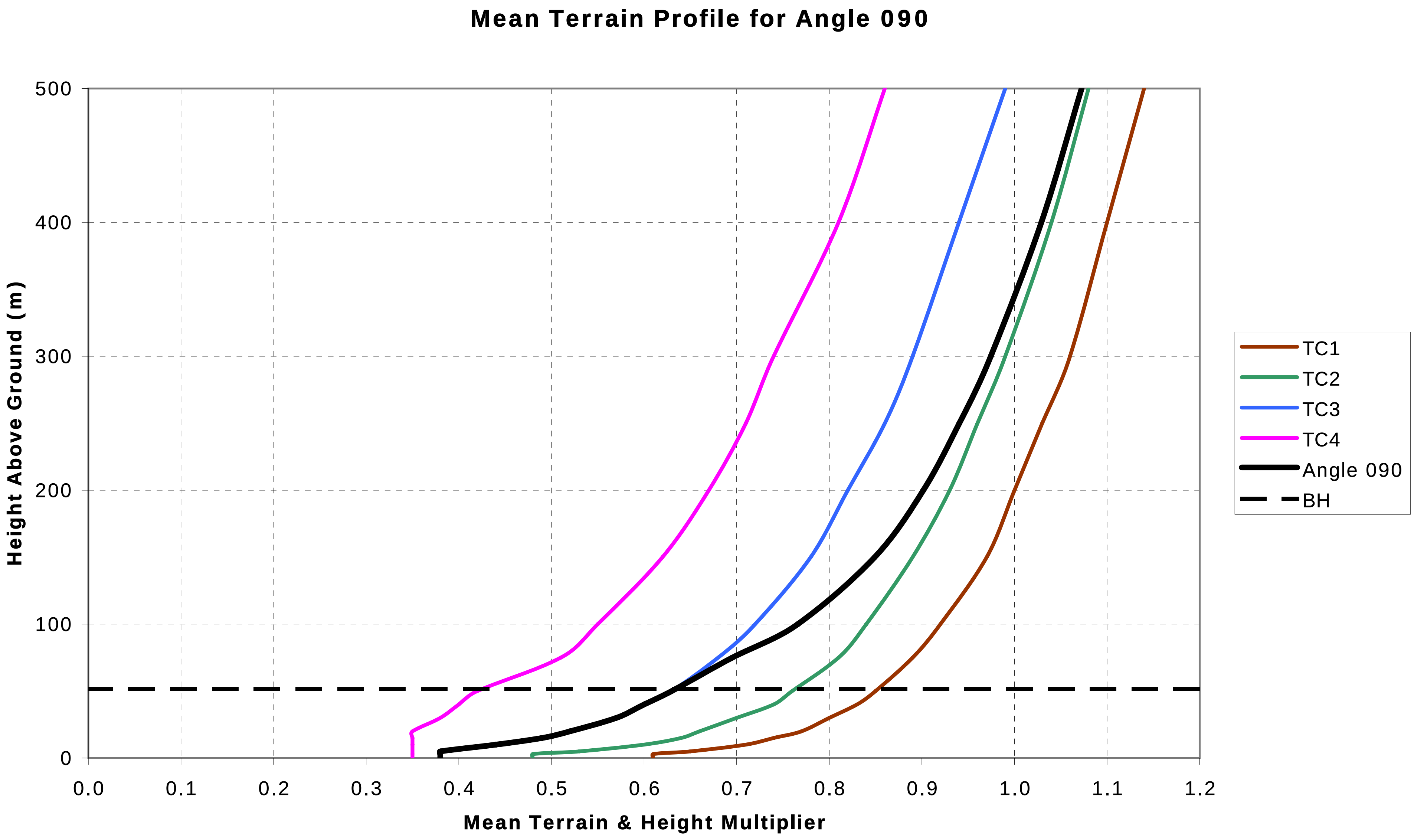
Mean Terrain Profile for Angle 022.5
Height Above Ground (m)
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 022.5
BH

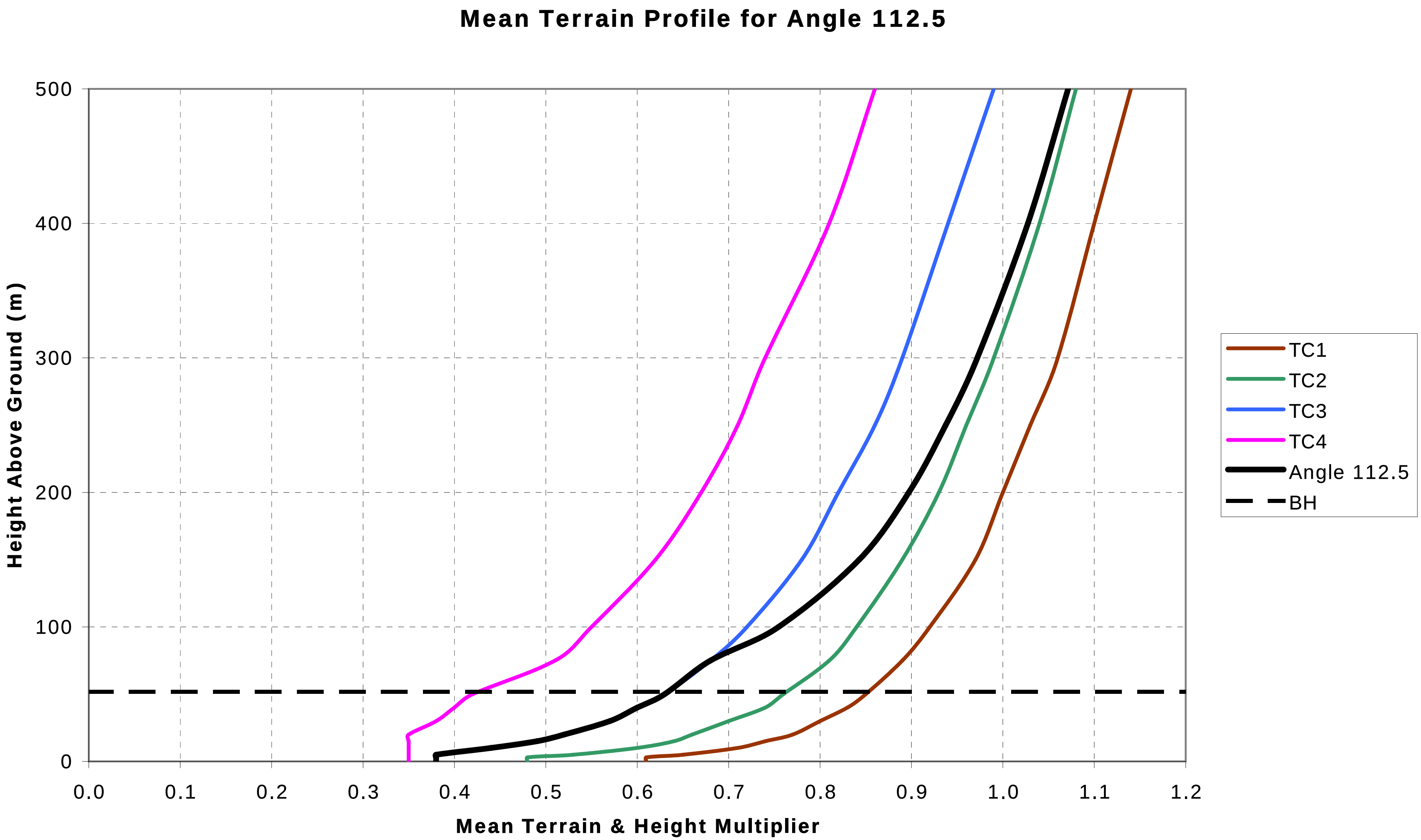


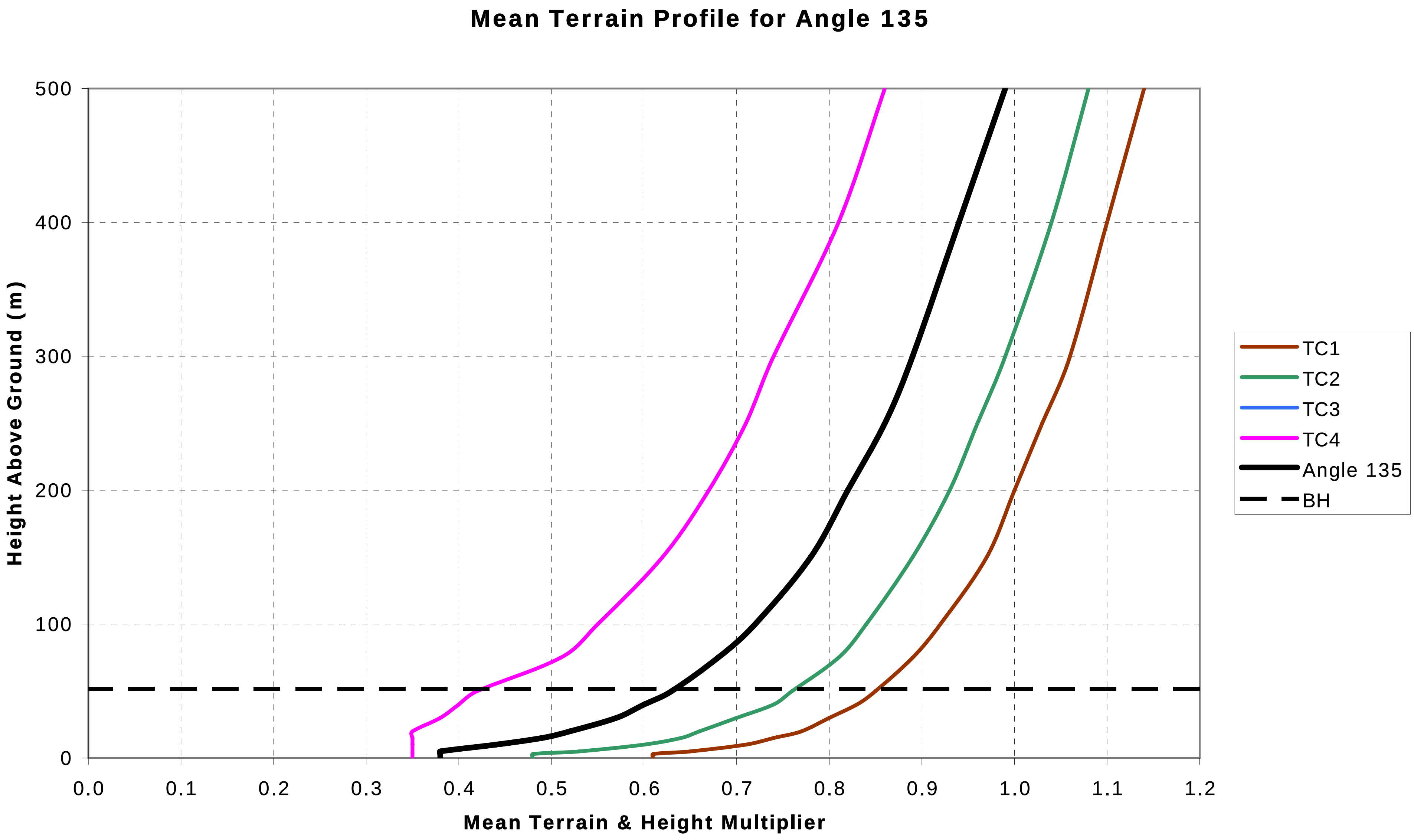
Mean Terrain Profile for Angle 045
Height Above Ground (m)
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 045
BH

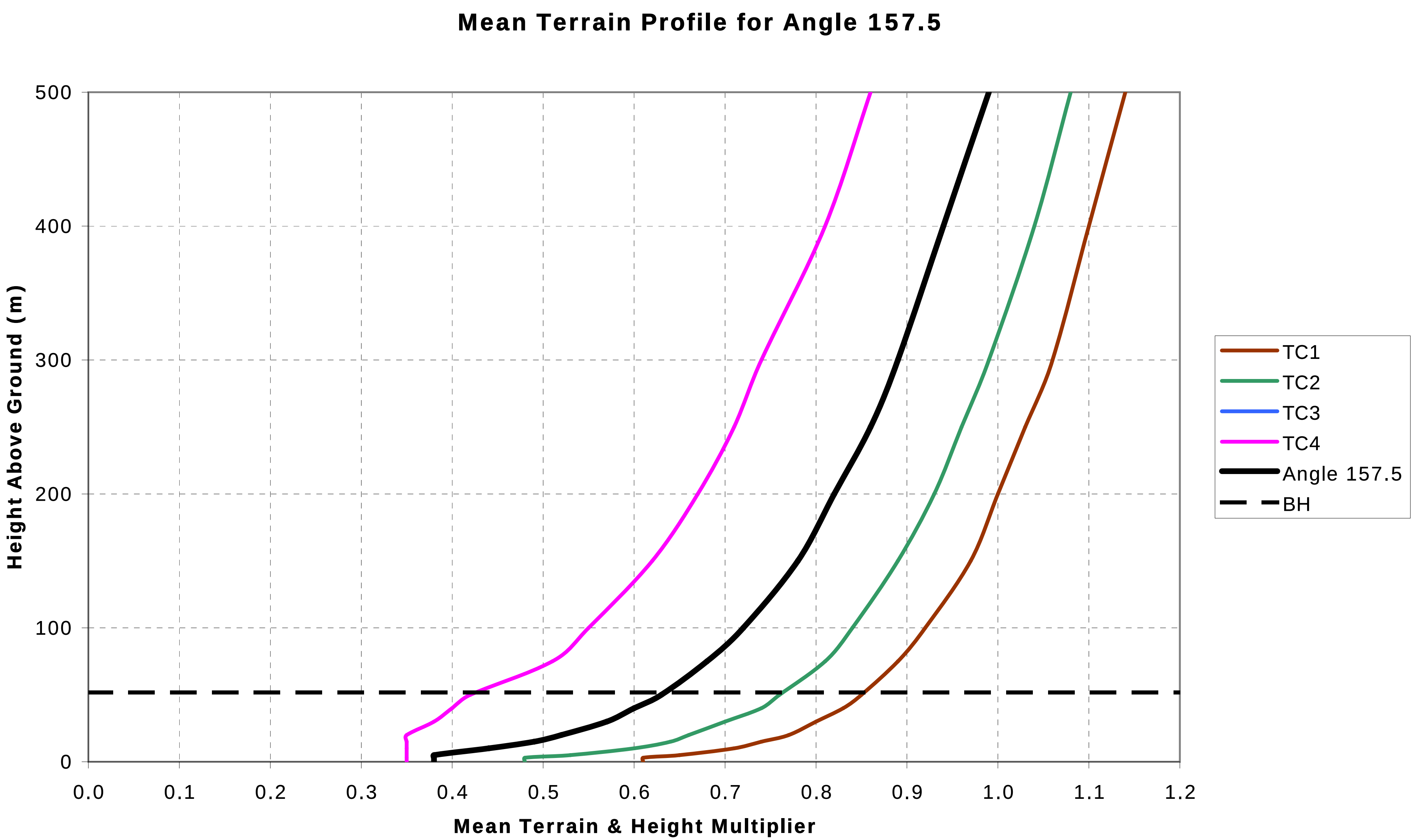


Mean Terrain Profile for Angle 067.5
Height Above Ground (m)
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 067.5
BH

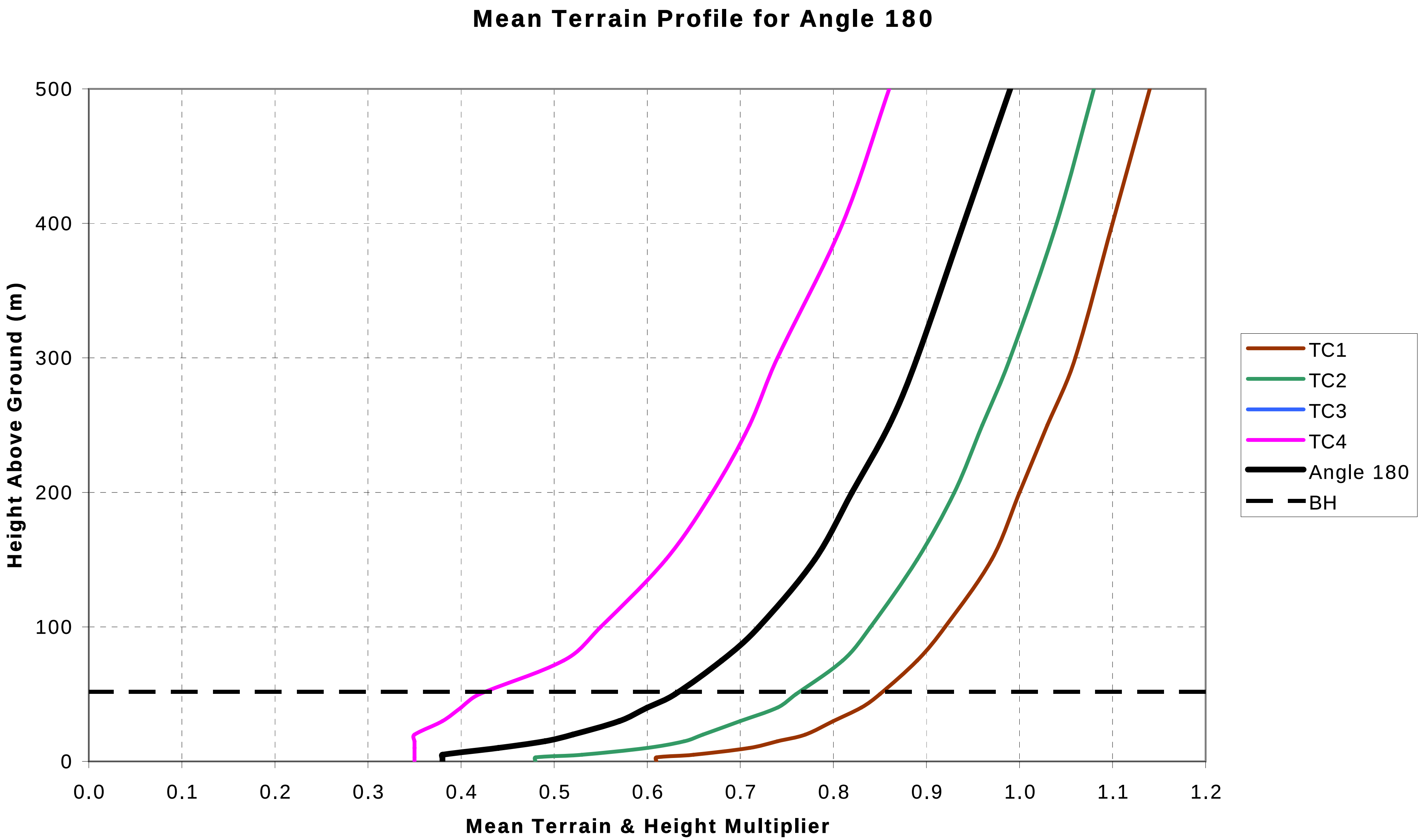

Mean Terrain Profile for Angle 090
Height Above Ground (m)
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 090
BH

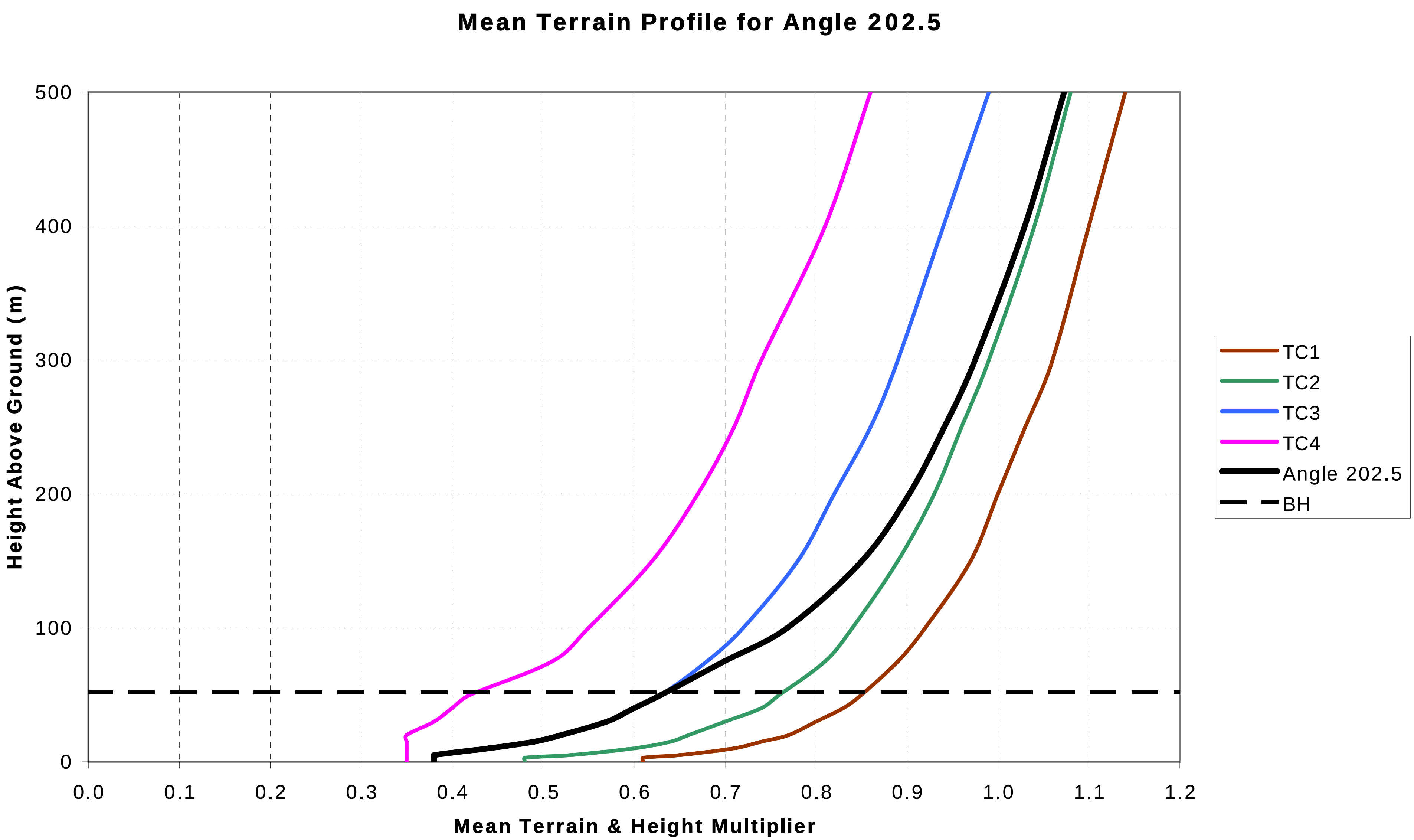

Mean Terrain Profile for Angle 112.5
Height Above Ground (m)
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 112.5
BH


Mean Terrain Profile for Angle 135
Height Above Ground (m)
0
100
200
300
400
500
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 135
BH

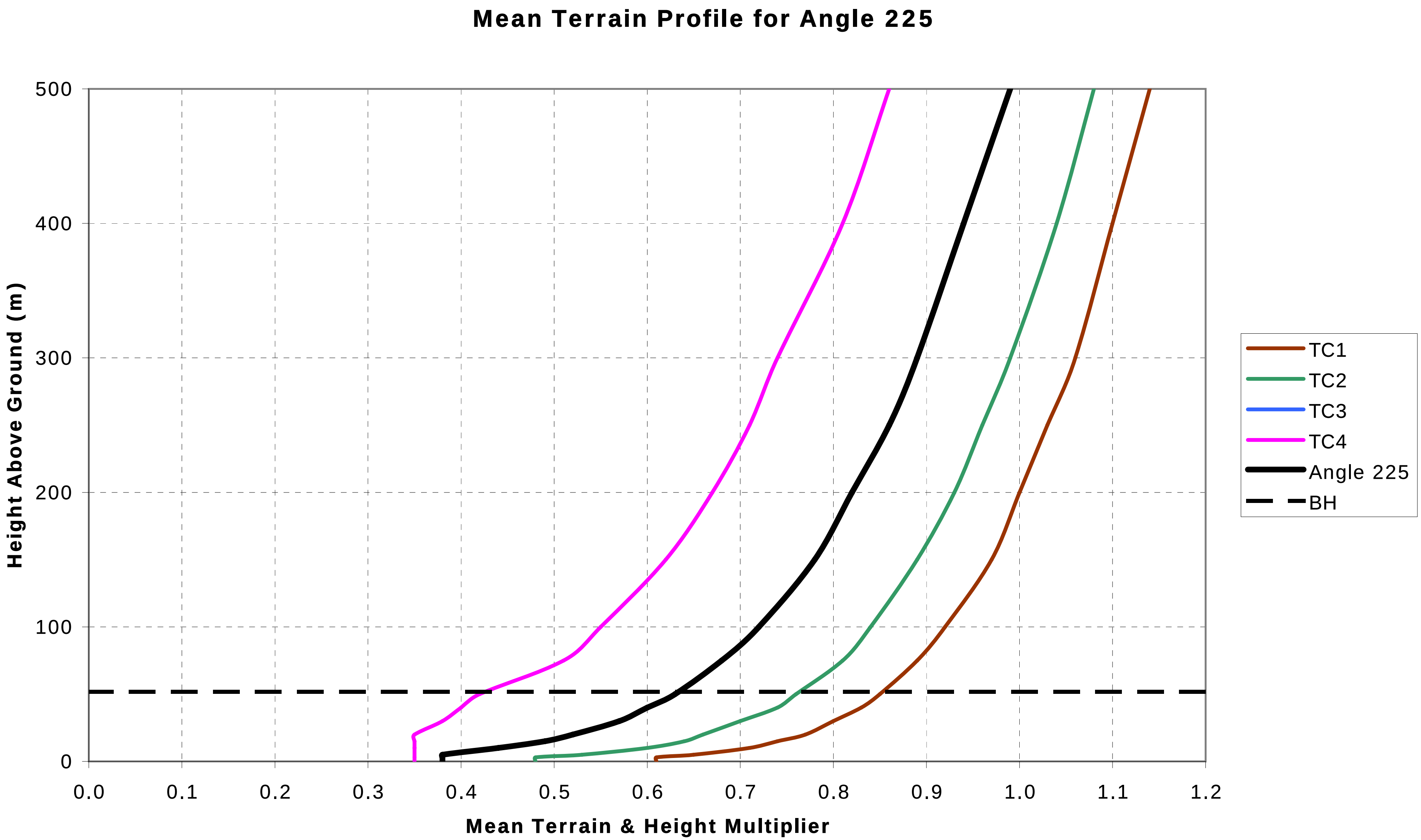


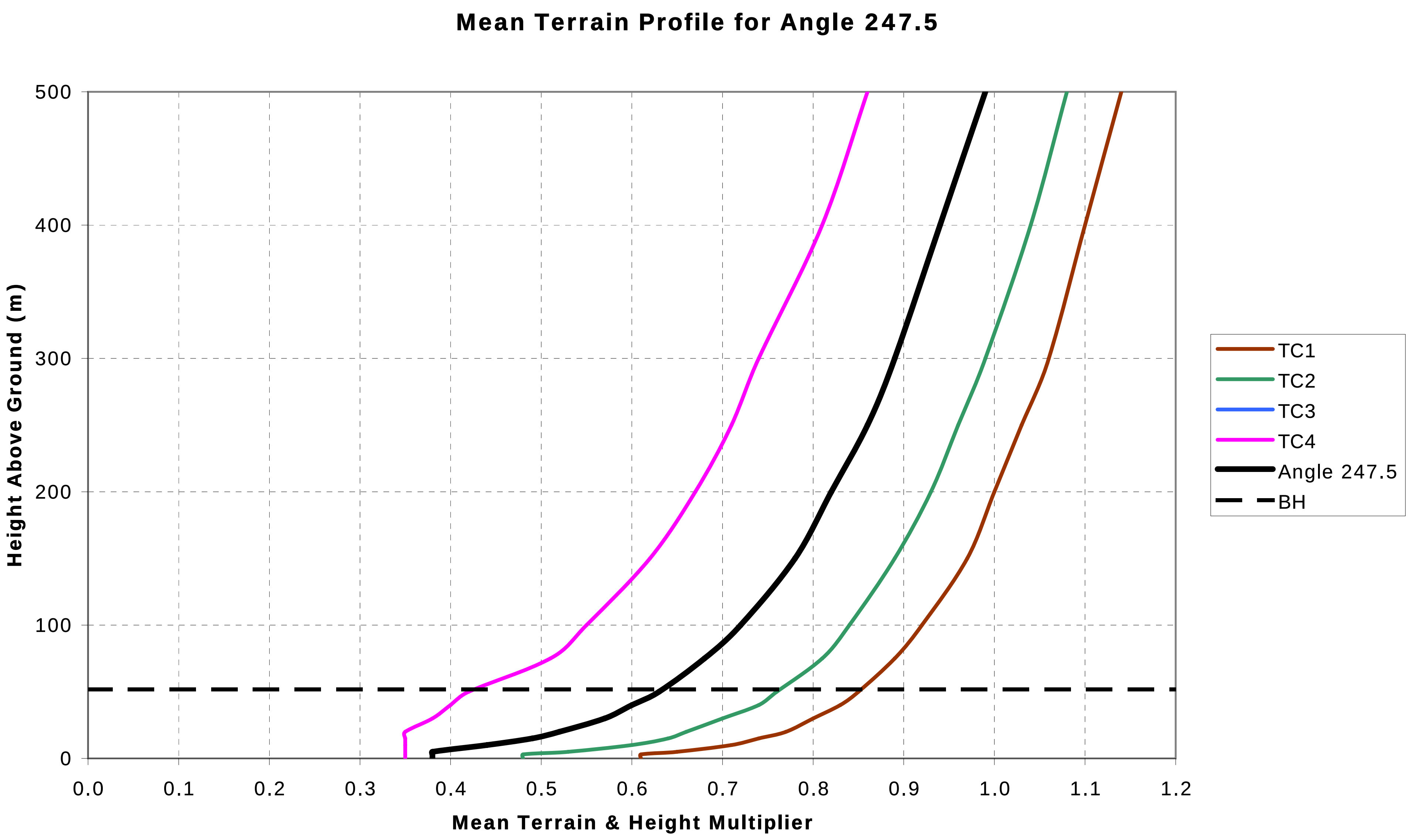
Mean Terrain Profile for Angle 157.5
Height Above Ground (m)
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 157.5
BH

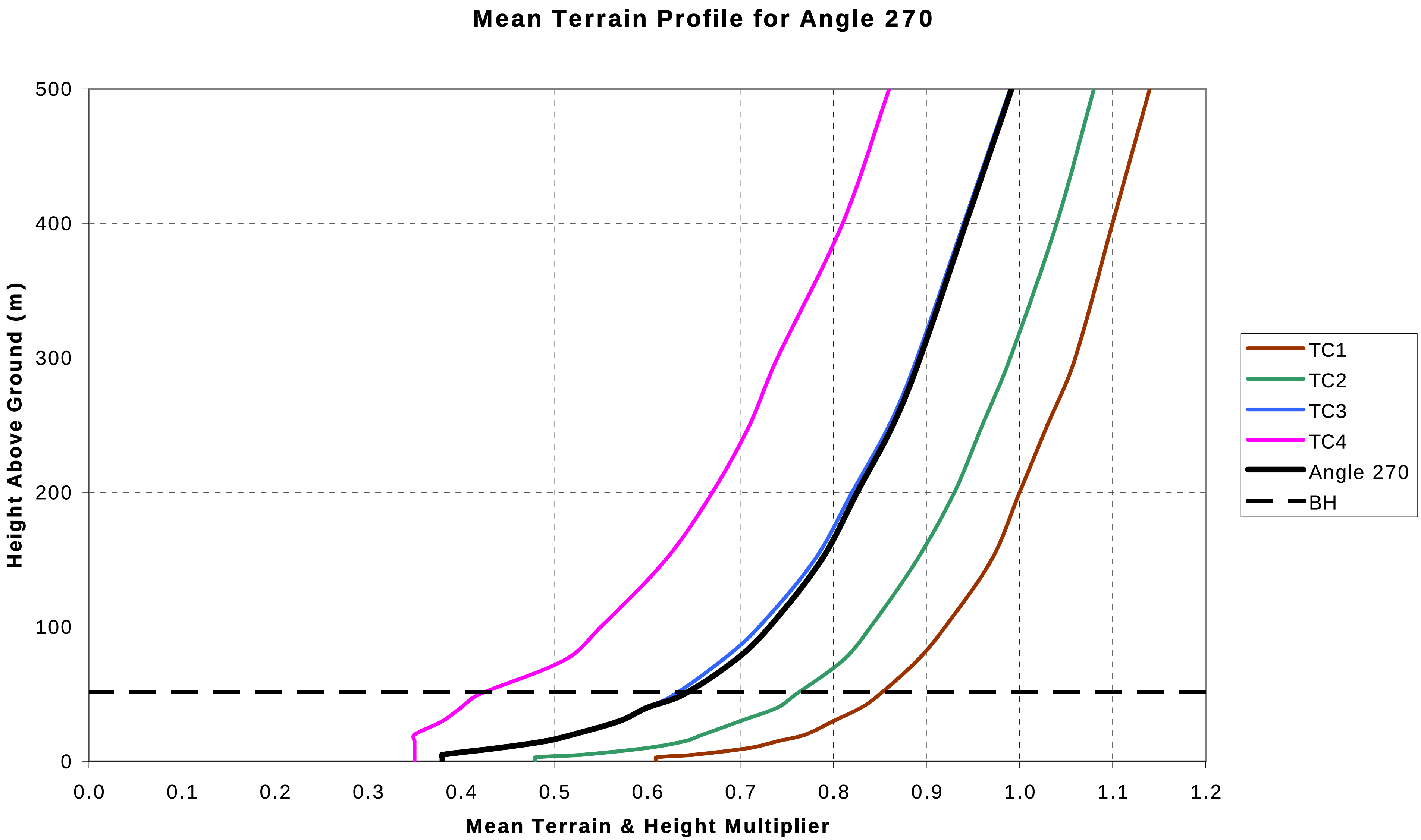

Mean Terrain Profile for Angle 180
Height Above Ground (m)
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 180
BH



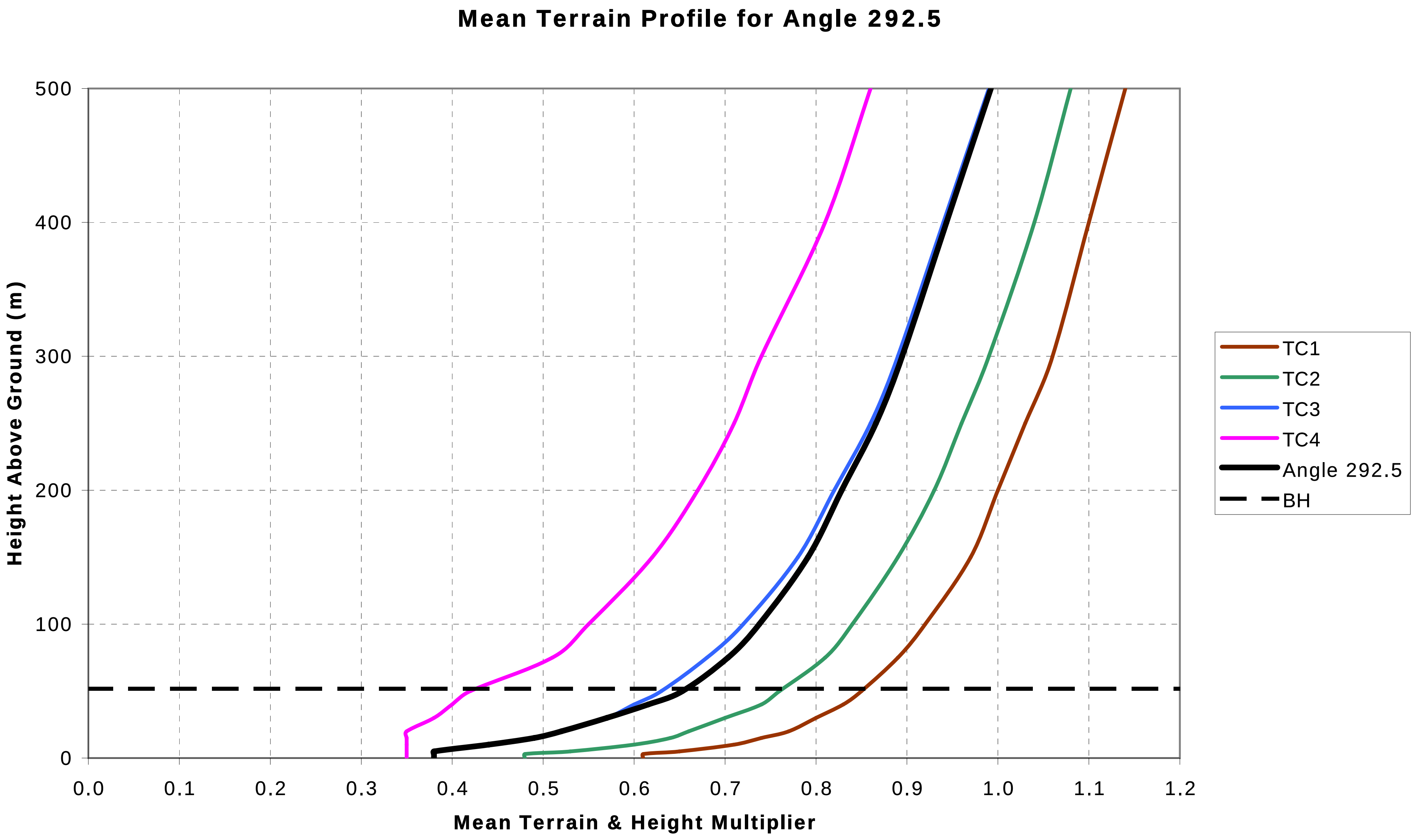
Mean Terrain Profile for Angle 202.5
Height Above Ground (m)
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 202.5
BH


Mean Terrain Profile for Angle 225
500
400
300
200
100
0
Height Above Ground (m)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 225
BH

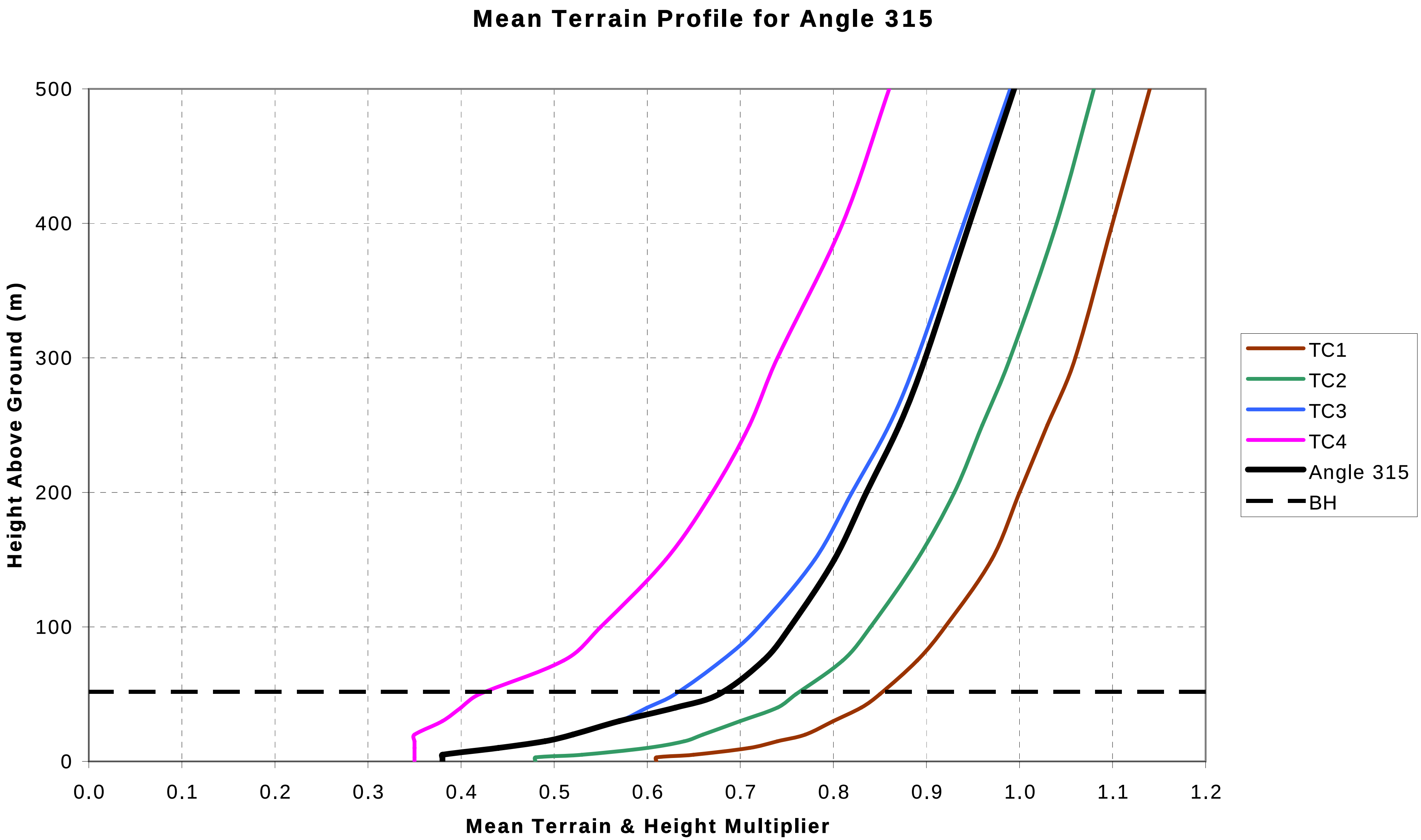

Mean Terrain Profile for Angle 247.5
Height Above Ground (m)
0
100
200
300
400
500
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 247.5
BH

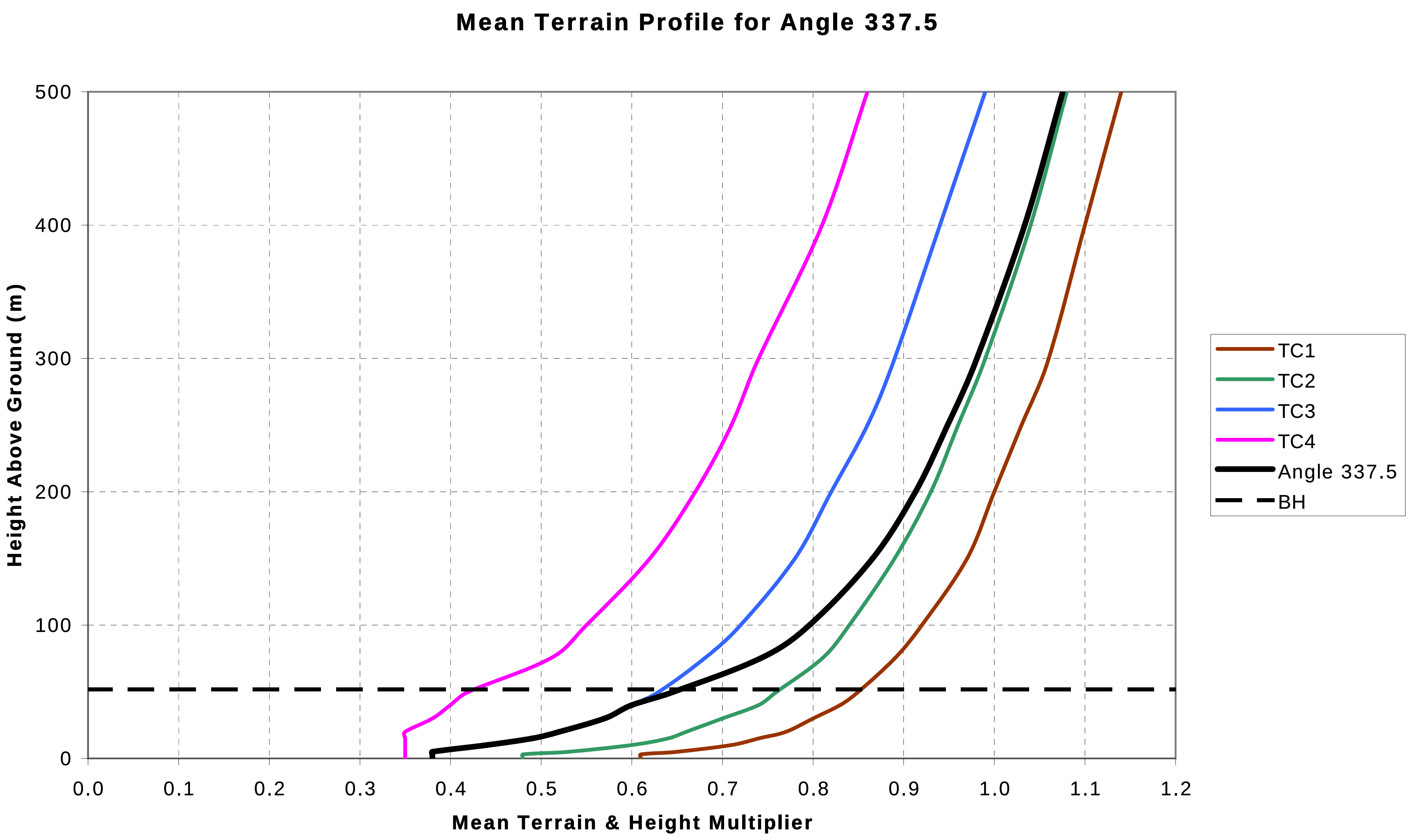


Mean Terrain Profile for Angle 270
Height Above Ground (m)
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 270
BH



Mean Terrain Profile for Angle 292.5
Height Above Ground (m)
0
100
200
300
400
500
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 292.5
BH


Mean Terrain Profile for Angle 315
Height Above Ground (m)
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 315
BH



Mean Terrain Profile for Angle 337.5
Height Above Ground (m)
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mean Terrain & Height Multiplier
TC1
TC2
TC3
TC4
Angle 337.5
BH