WINDTECH

Pedestrian Wind Environment Study

for the proposed development at

1-17 Elsie St, Burwood

August 12, 2008

Report Reference No. WA322-02F03(rev0) - WE Report.doc

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

Document Control

Revision Number	Date	Revision History	Prepared By (initials)	Initial Review By (initials)	Reviewed & Authorised By (initials)
0	12/08/2008	Initial	NT	AB	TR

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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 known as 1-17 Elsie Street, located between Victoria, Elsie and George Streets, Burwood.

Wind speed measurements were carried out using a 1:400 scale model of the development. Surround models incorporating the existing neighbouring buildings and local land topography were placed around the model of the site. The surrounds model extends to a radius of approximately 500m from the site.

The results of the study indicate that wind conditions for most of the site are acceptable for their intended uses. Treatments have been recommended in this report for several areas of the development to mitigate against adverse wind effects. The treatments recommended in this report are summarised as follows:

- The addition of two densely foliating trees (capable of growing to approximately 6m tall with a 4m wide canopy) at ground level near the north-western corner of the site.

- The addition of several densely foliating trees (capable of growing to approximately 6m tall with a 4m wide canopy) at ground level on the western edge of site, within the private recreation area.

- The addition of several densely foliating trees (capable of growing to approximately 5m tall with a 4m wide canopy) on the Level 3 podium as indicated in Figure 7b.

- Impermeable full height screens or impermeable operable louvers on the southern edge of the south facing balconies of the southern tower.

Note that for the trees to be effective in mitigating against westerly, winds which are typically prevalent during the winter months for the Sydney region, evergreen should be used. The species of trees selected should also be of a densely foliating variety. Palm trees, for example, would not be effective in wind mitigation to ground level areas.

With the addition of the treatments listed above, all outdoor trafficable areas within and around the proposed development will be acceptable for their intended use.

2.0 Model Description

Wind speed measurements were carried out using a 1:400 scale model of the development. A surrounds model incorporating the neighbouring buildings and local land topography was placed around the study building model. The surrounds model extends to a radius of 500m from the site. Photographs of the wind tunnel model are presented in Figures 1a to 1d. The model was placed in open and suburban terrain boundary layer wind flows based on the Deaves and Harris model. The reference wind speeds were corrected for changes in the upstream building morphology and land topography.

The tower reference height used in this study is approximately 57m above ground. The boundary layer wind flows matched the model scale and the overall surrounding terrain characteristics beyond the 500m 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 40h from the site, where h is the height of the tower. Hence, for this project, the fetch length is 1780m. The terrain types indicated in Figure 2 are classified as either open, suburban or urban.

Figure 1a: Photograph of the Model in the Wind Tunnel (View from the South)

Figure 1b: Photograph of the Model in the Wind Tunnel (View from the East)

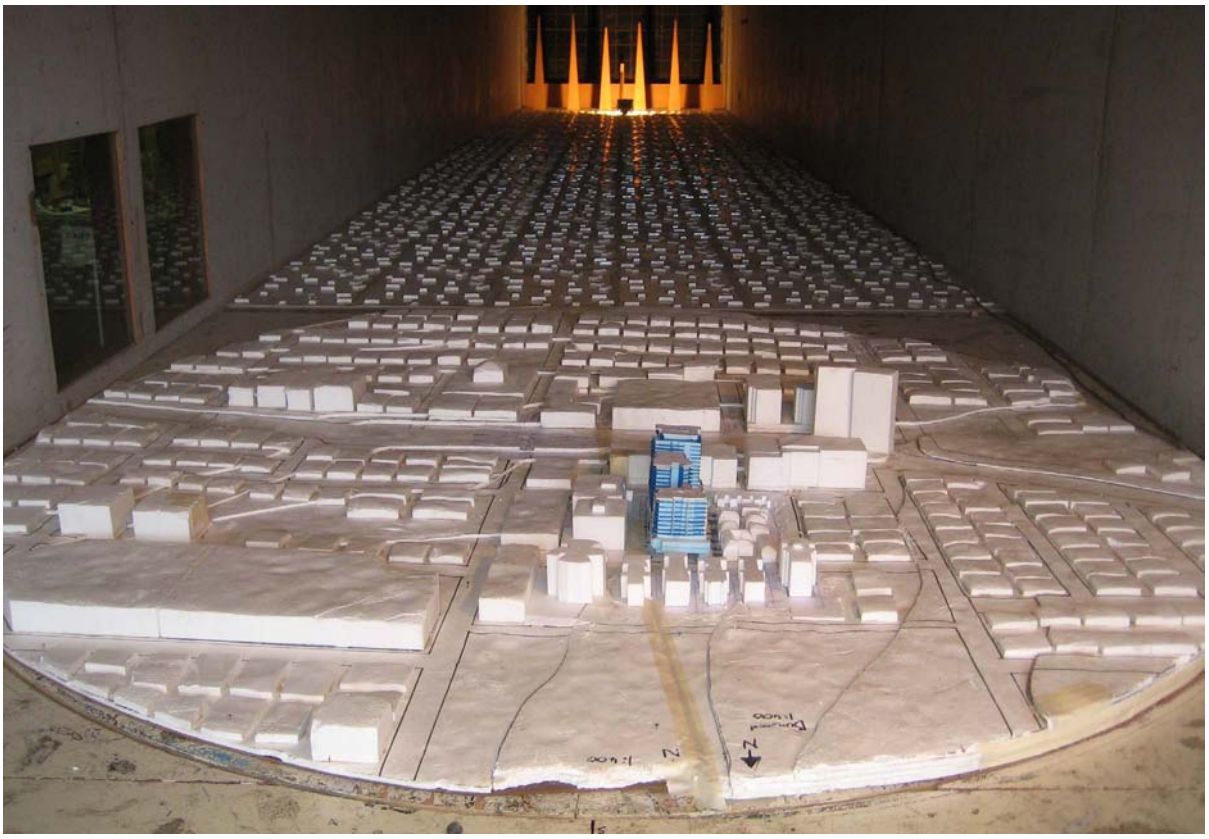

Figure 1c: Photograph of the Model in the Wind Tunnel (View from the North)

Figure 1d: Photograph of the Model in the Wind Tunnel (View from the West)

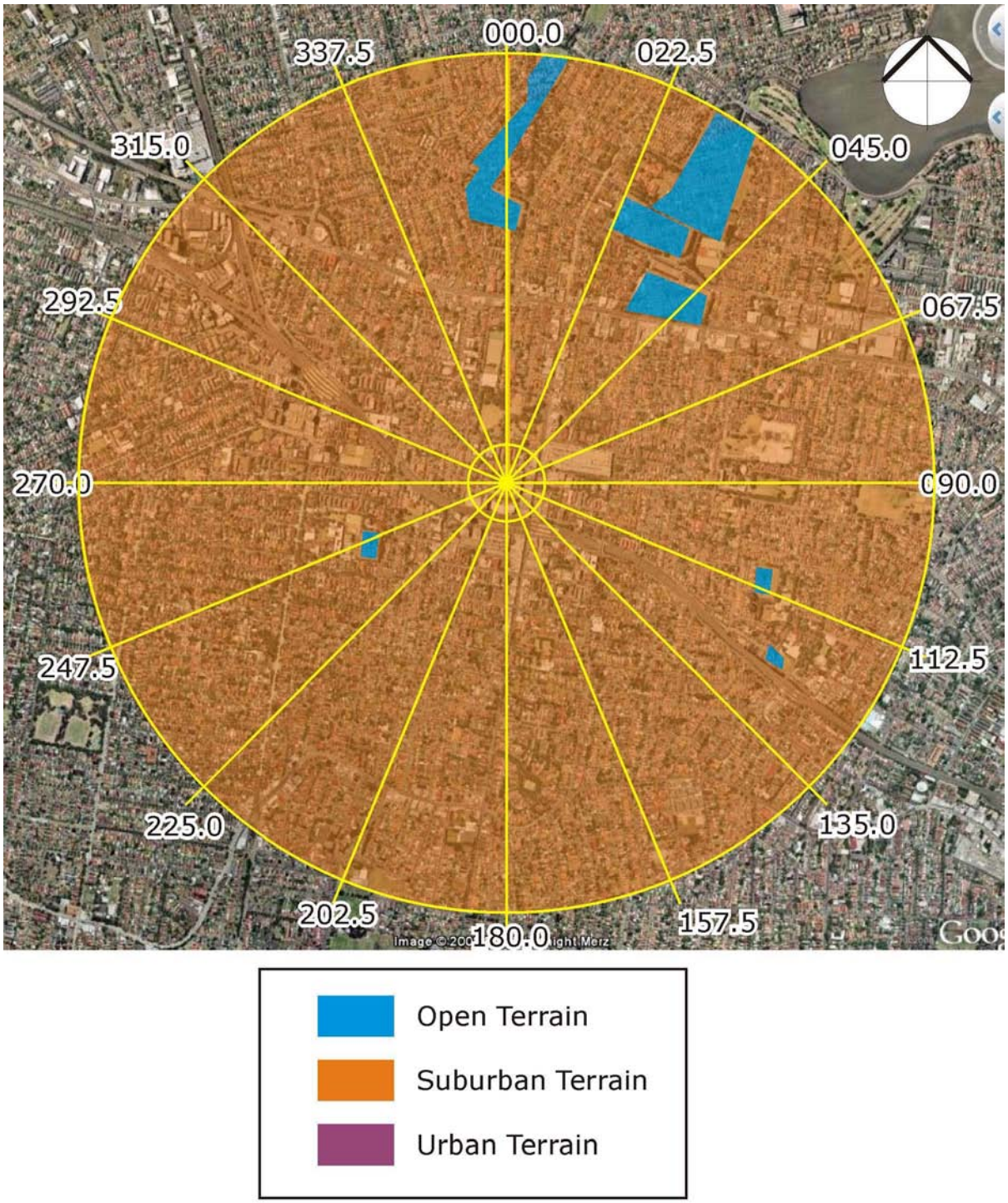

Figure 2: Aerial Image of the Site and Surrounds (terrain categories also shown)

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.

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, for wind coming from 000 degrees (a northerly wind), it is assumed that the approaching wind profile at the edge of the study zone (1780m from the site for this study) is the standard Deaves and Harris (1978) suburban terrain profile, since this is coming from over the residential area to the north of the site. The wind continues over the suburban terrain for approximately 250m, when the wind reaches a section of parkland, where the Deaves and Harris (1978) open terrain is most appropriate. The wind profile begins to adapt from the open terrain profile to the suburban terrain profile. By the lag distance equation, at a height of 100m above ground, the profile requires 2130m to fully change to the standard Deaves and Harris (1978) open terrain profile. However, the open terrain only goes for approximately 250m before the wind again reaches suburban terrain which continues until the edge of the site. Hence, by the time the wind reaches the end of the section of suburban terrain, at a height of 50m above ground, the profile is 28% developed into the open terrain wind profile from the suburban wind profile. At 100m above ground it is only 12% developed, and at 15m above ground it is 100% developed. The wind profile plot in Appendix B for wind angle 000 shows that by the time the wind reaches the site the profile approximates a Deaves and Harris (1978) suburban profile both above and below building height.

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

The Deaves and Harris (1978) terrain category defines the wind tunnel setup that was used to replicate the upstream wind flow (velocity profile and turbulence intensity) approaching the model for each direction tested.

3.0 Test Procedure

Testing was performed in Windtech's blockage tolerant 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 11m/s. This corresponds to a minimum velocity scale of between 1:1.2 and 1:2.1 for the annual maximum peak wind speeds for the Sydney region. Hence the sample length in the model scale of 12 seconds is equivalent to between approximately 37 and 69 minutes in full-scale.

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 mounting to avoiding wall-heating effects.

The mean and the maximum 3 second duration peak gusts 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, mean wind speeds were measured at selected points at a 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 wind speed measurements to actual gust velocities, based on available meteorological data for Sydney. 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 the standard Deaves and Harris (1978) suburban terrain model and a reference height of 200m are given in Figure 3.

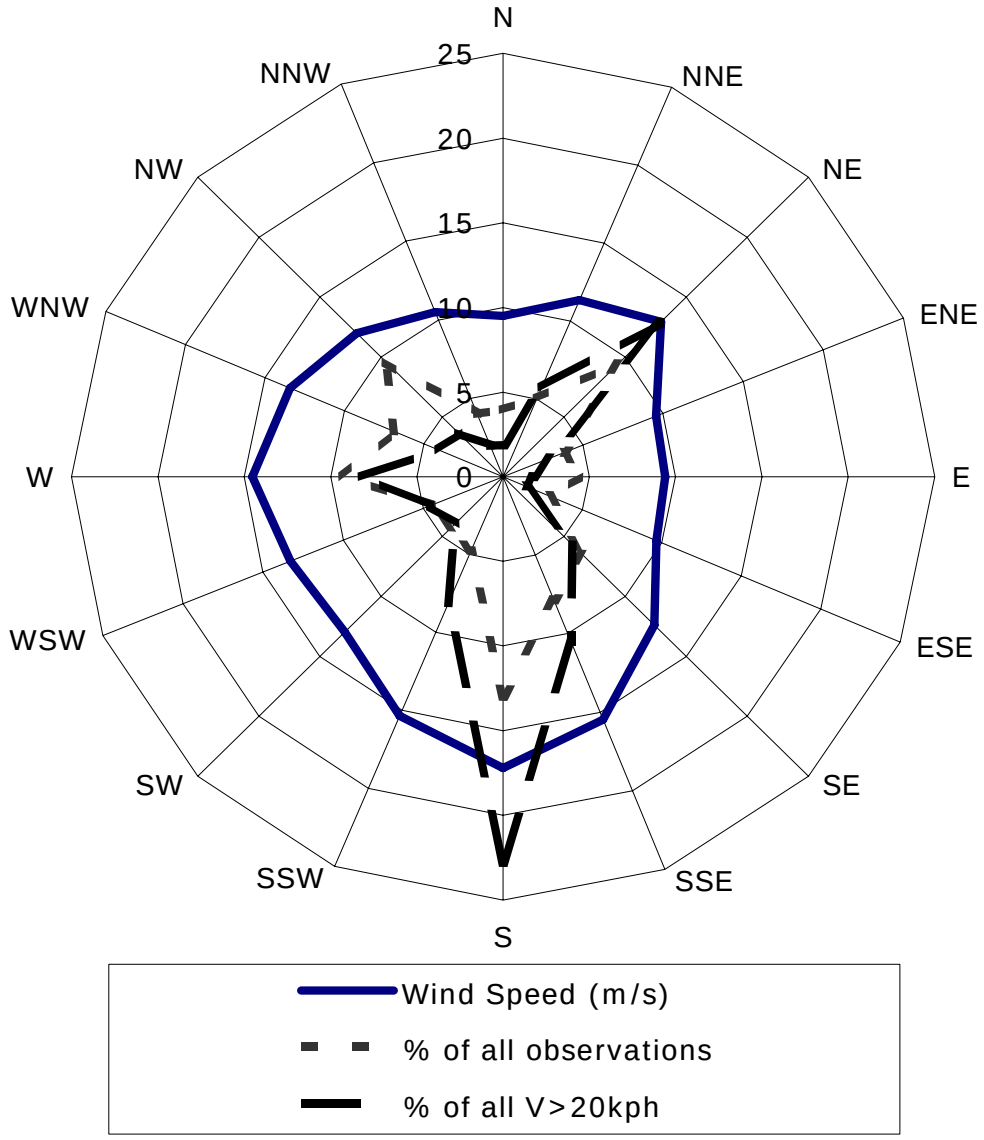

Figure 3: Annual Maximum Mean Wind Speeds for Sydney

(based on 10 minute means, corrected for suburban terrain at a reference height of 200m)

Sydney Airport Observation Office, 1939 to 1992

4.0 Environmental Wind Speed Criteria

The three principal wind directions affecting this development prevail from the North-East, South and West. Table 1 is a summary of the principal time of occurrence of these winds. A full set of wind roses for the Sydney region, obtained from Sydney Airport (1939 to 2000) at 9am and 3pm for each month throughout the year, are attached in Appendix A of this report.

Table 1: Principle Time of Occurrence of Wind for the Sydney Region

Month	Wind Direction		
	North-Easterly	Southerly	Westerly
January	X	X	
February	X	X	
March	X	X	
April		X	X
May			X
June			X
July			X
August			X
September		X	X
October	X	X	
November	X	X	
December	X	X	

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	Wind Speed (m/s)	Effects	Applicability
Calm, light air	1	0 - 1.5	Calm, no noticeable wind	Generally acceptable for stationary, long exposure activities such as in outdoor restaurants & theatres.
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	Generally acceptable for walking & stationary, short exposure activities such as window shopping, standing or sitting in plazas.
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.	Acceptable for comfortable walking as in main public accessways.
Gale	8	17.2 -20.7	Generally impedes progress, Great difficulty with balance.	Unacceptable as main public accessways.
Strong gale	9	20.8 - 24.4	People blown over by gusts.	Completely unacceptable.

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.

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 < *u* < 10 m/s
Strolling, Skating	Slow walking, etc.	5.5 m/s < *u* < 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 < *u* < 5.5 m/s
Long Exposure Activities	Generally acceptable for long duration stationary activities such as in outdoor restaurants & theatres and in parks.	*u* < 3.5 m/s

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: 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 < *u* < 10 m/s
Pedestrian Walking	Slow walking, etc.	6 m/s < *u* < 8 m/s
Short Exposure Activities	Pedestrian Standing or sitting for a short time	4 m/s < *u* < 6 m/s
Long Exposure Activities	Pedestrian sitting for a long duration	*u* < 4 m/s

Table 4b: 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

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.	u > 23m/s
Marginal	Unacceptable as main public accessways.	16 m/s < u < 23 m/s
Comfortable Walking	Acceptable for walking, main public accessways	13 m/s < u < 16 m/s
Short Exposure Activities	Generally acceptable for walking & short duration stationary activities such as window-shopping, standing or sitting in plazas.	10 m/s < u < 13 m/s
Long Exposure Activities	Generally acceptable for long duration stationary activities such as in outdoor restaurants & theatres and in parks.	u < 10 m/s

4.4 Comparison of the Various Wind Speed Criteria

The criteria mentioned in Tables 2 to 5, as well as other criteria, are compared on a probabilistic basis in Figure 4, below.

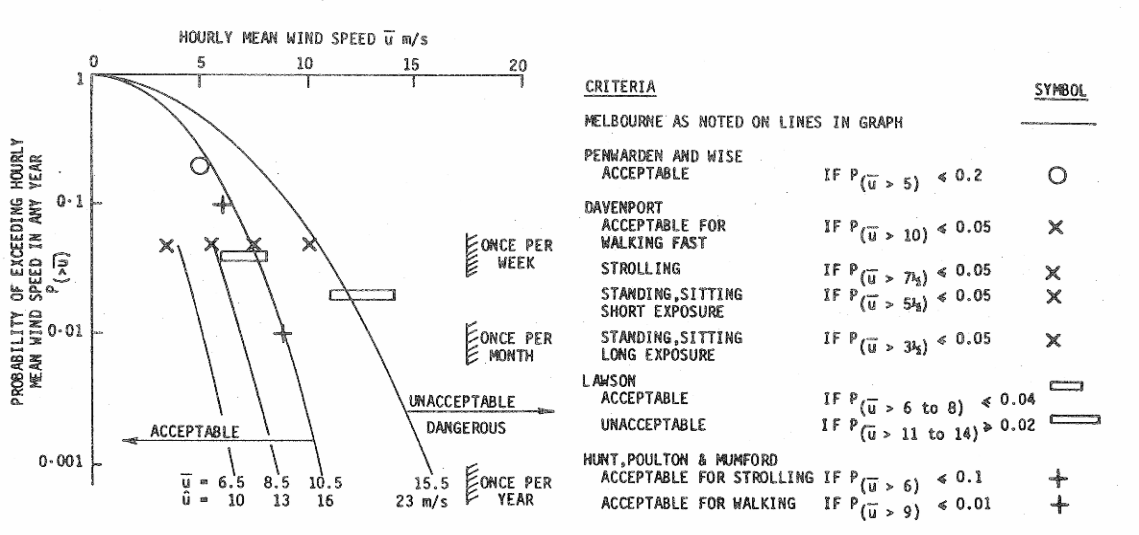

Figure 4: Comparison of Various Mean and Gust Wind Environment Criteria, assuming 15% turbulence and a Gust Factor of 1.5 (after Melbourne, 1978)

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 is a lower bound estimate.

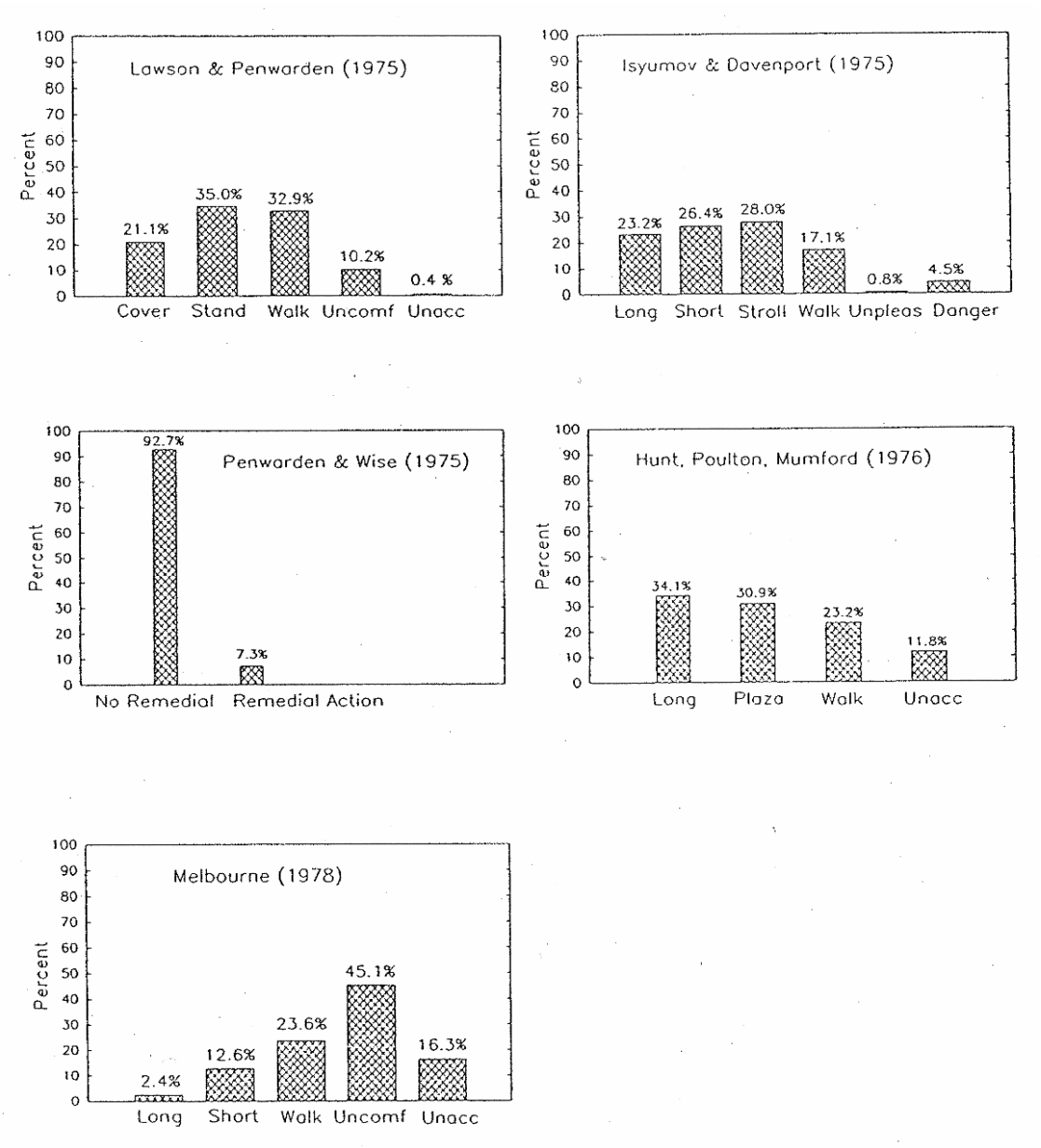

Figure 5: Distribution of Pedestrian Wind Comfort over Five Criteria for 246 locations examined in the Wind Tunnel (after Ratcliff & Peterka, 1990)

4.6 Criteria Used For This Study

For the purposes of this study the local wind conditions within and around the development has been based on the following criteria (see also Figures 6a to 6c):

- 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 4).

- The private ground level outdoor areas on the western side of the site that adjoins the neighbouring buildings are compared against the Davenport (1972) **short exposure** criterion of 5.5m/s for GEM wind speeds (see Table 2). The remainder of the ground level outdoor areas is compared against the Davenport (1972) **comfortable walking** criterion of 7.5m/s for GEM wind speeds (see Table 2).

- The recreational area in the centre section of level 3 podium is compared against the Davenport (1972) **short exposure** criterion of 5.5m/s for GEM wind speeds (see Table 2). The northern and southern sides of the level 3 podium that adjoin the private balconies are compared against the Davenport (1972) **comfortable walking** criterion of 7.5m/s for GEM wind speeds (see Table 2).

- The private balconies on all three towers are compared to the Melbourne (1978) **Safety Limit** criterion of 23m/s for an annual maximum peak wind speed (see Table 4).

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.

Notes:

- Long Exposure typically applies to outdoor activities such as dining areas for restaurants, amphitheatres etc.
- Short Exposure typically applies to areas where short duration stationary activities are involved (less than 1 hour). This includes parks and landscaped areas, window shopping, waiting and drop-off areas.
- Comfortable Walking typically applies to main pedestrian thoroughfares
- Fast walking typically applies to infrequently used laneways, and possibly balconies, private terraces etc.
- In all areas, the wind conditions are also checked against the safety limit.

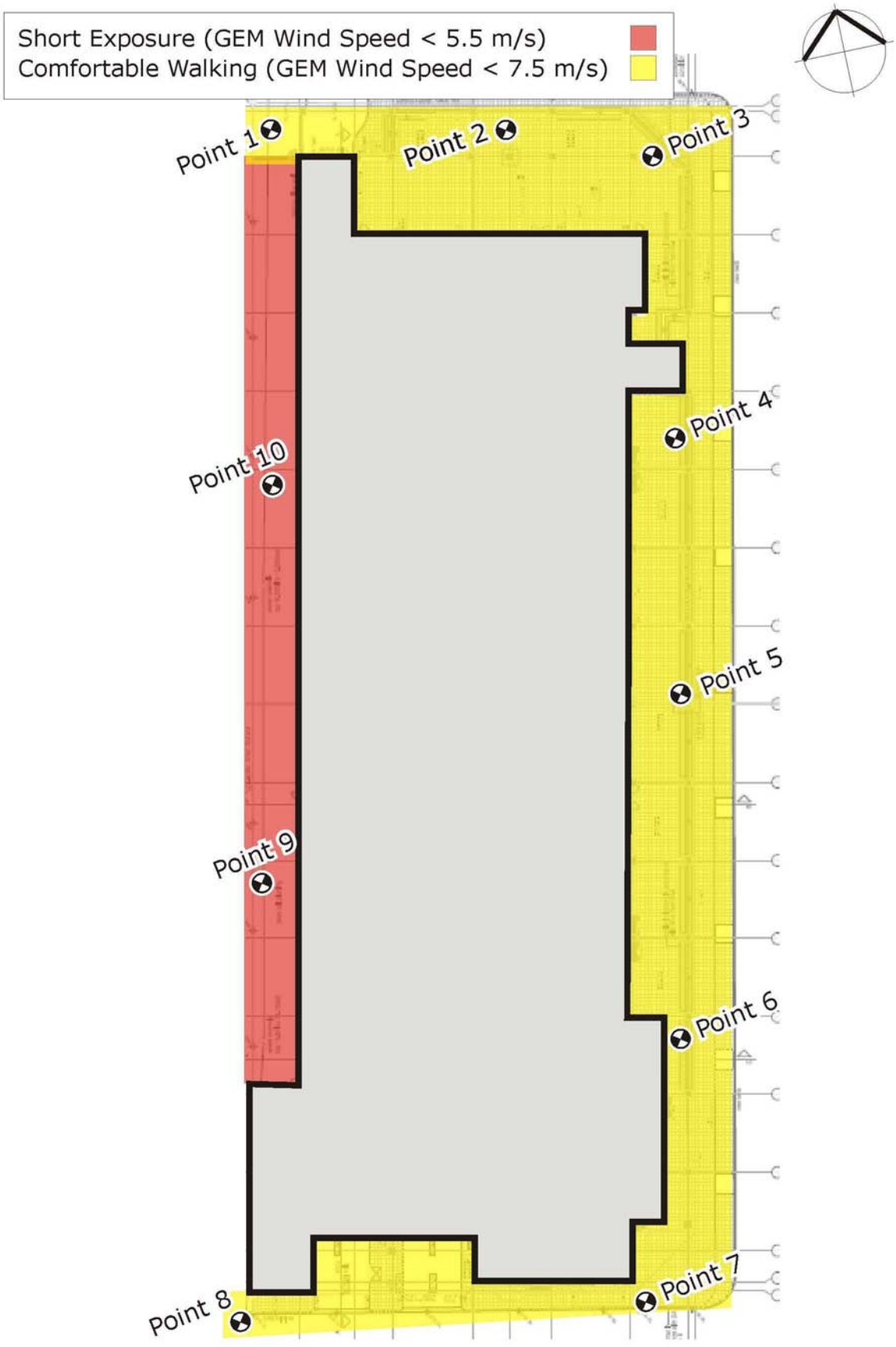

Figure 6a: Study Point Locations & Wind Comfort Criterion Zones Ground Level

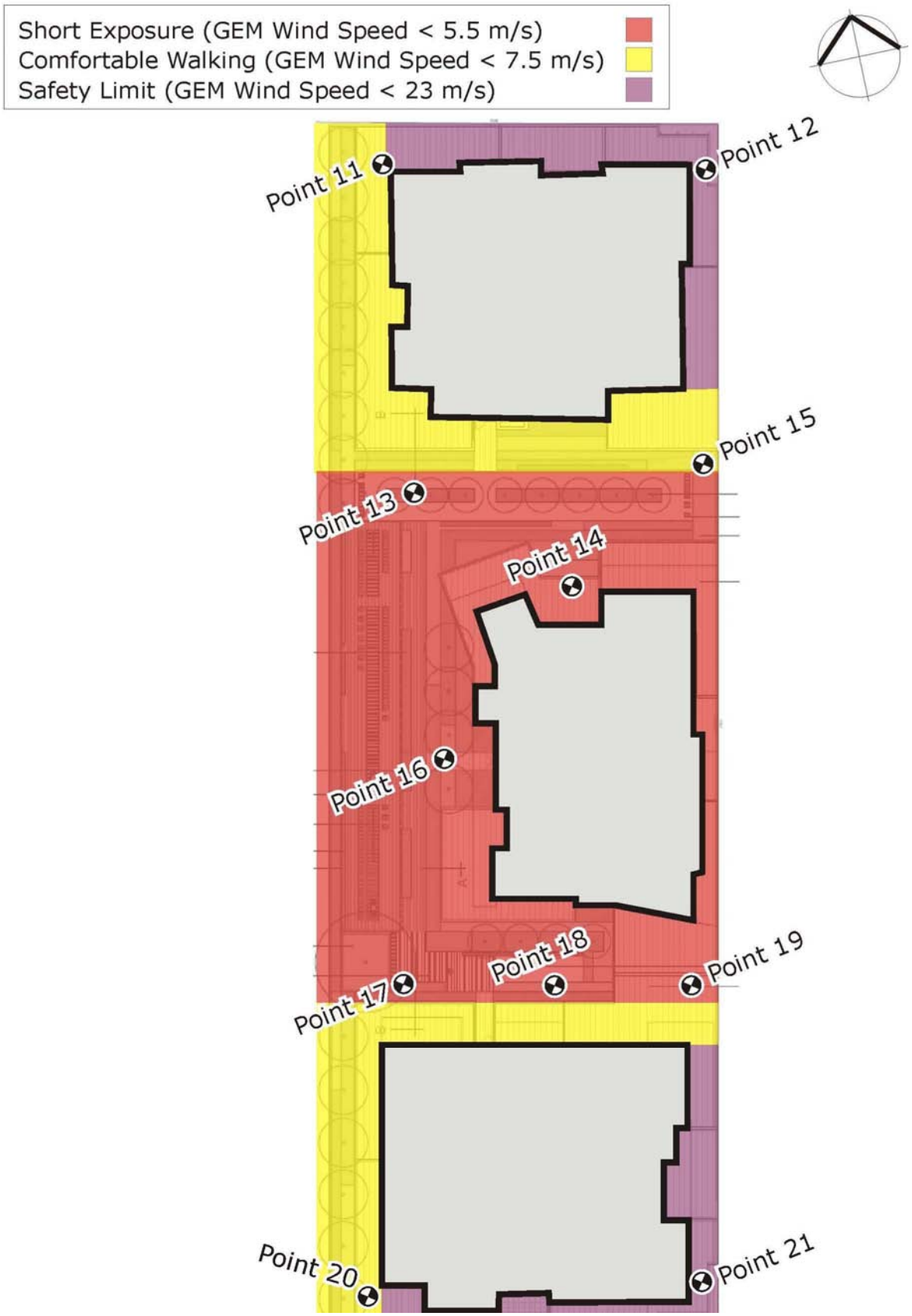

Figure 6b: Study Point Locations & Wind Comfort Criterion Zones Level 3 Podium

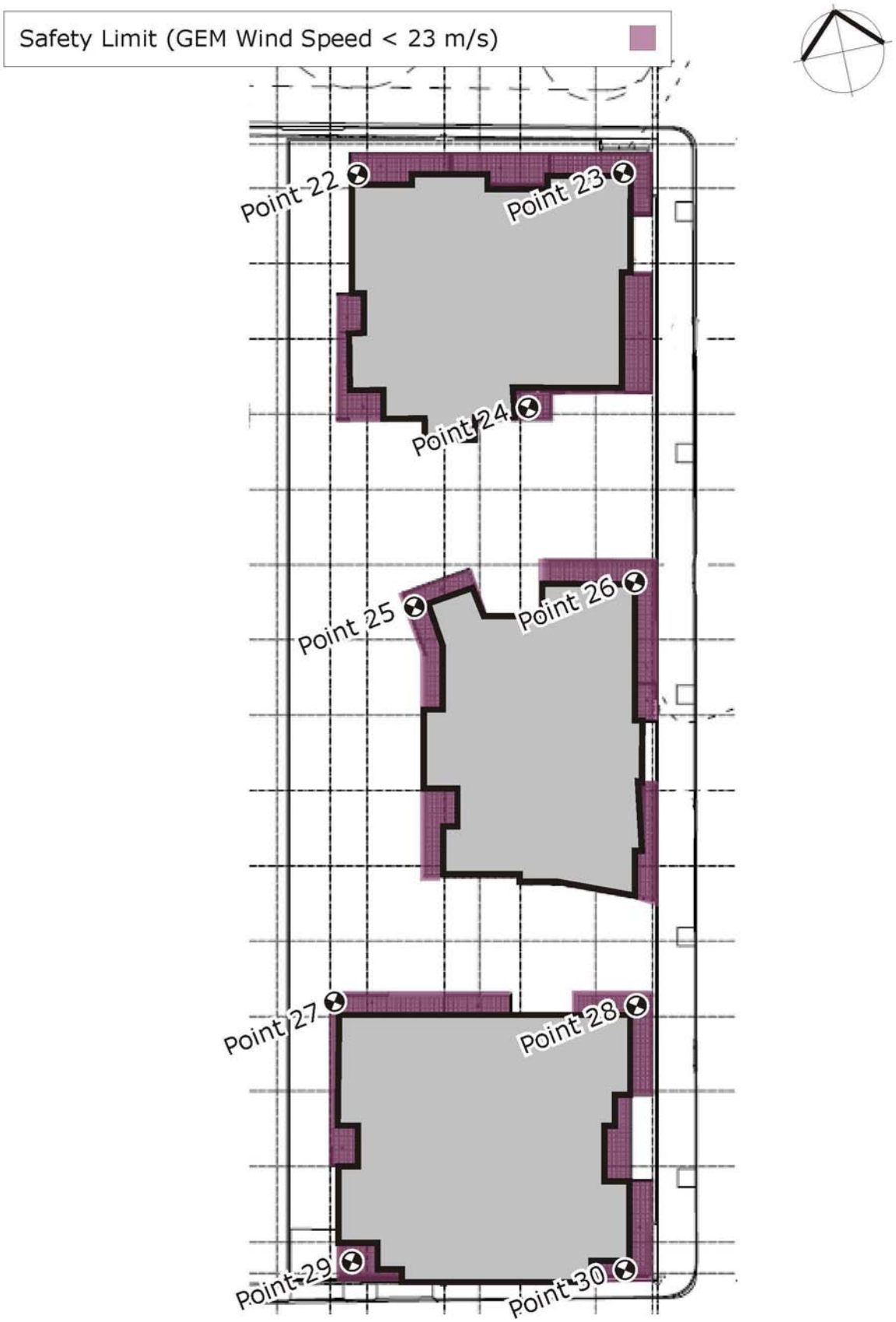

Figure 6c: Study Point Locations & Wind Comfort Criterion Zones Private Balconies of the Tower Levels

5.0 Results of Study

A detailed study of wind activity around and within the proposed development was carried out. A total of 30 study locations were chosen for detailed analysis, as shown in Figures 6a to 6c. The proposed development was initially tested without the effect of any wind ameliorating devices, such as vegetation or additional screens/awnings not shown on the architectural drawings. For areas not achieving the appropriate wind conditions, retests were conducted with some form of treatment.

Plots of the results for the local directional wind speeds for the various test point locations, as derived from the wind tunnel tests, are presented in Appendix B of this report. These results are separated into two plots; maximum weekly GEM wind speeds based on the Davenport (1972) criteria, and annual maximum peak wind speeds based on the Melbourne (1978) criteria.

5.1 Ground Level Areas

The Study Points:

Points 1 to 10 were used to monitor the wind conditions at the various ground level outdoor areas within and around the site. The locations of these points are summarised as follows:

- Points 1 to 3 are located along the pedestrian path near Victoria Street, on the northern edge of the site.
- Points 4 to 6 are located along the pedestrian path near Elise Street, on the eastern edge of the site.
- Points 7 and 8 are located along the pedestrian path near George Street, on the southern edge of the site.
- Points 9 and 10 are located within the private recreation area on the western edge of the site.

The locations of these points are also shown in Figure 6a.

Applicable Criteria:

The appropriate wind comfort criterion for the pedestrian walking areas (Points 1 to 8) is the comfortable walking criterion of 7.5 m/s for weekly maximum GEM wind speeds. The appropriate wind comfort criterion for the remaining locations is the short exposure criterion of 5.5 m/s for weekly maximum GEM wind speeds.

In addition to the above criteria, wind conditions at all study points should also satisfy the Melbourne (1978) safety limit criterion of 23 m/s for annual maximum peak wind speeds.

Results and Recommendations:

The results indicate that the wind conditions for Points 2 to 8, which are located in pedestrian walking areas, will be acceptable for their intended use without the need for any treatments. Additionally Points 2 to 7 are within the short exposure criterion.

The results indicate that the wind conditions at Point 9, which is located in a short duration activity area, will be acceptable for its intended use without the need for any treatments.

The initial results for Point 1, which is located near the footpath on the north-western side of the site, indicate that the point is subjected to strong westerly and south-westerly winds. These wind conditions exceed the safety limit criterion of 23m/s for an annual maximum peak wind speed. With the addition of two densely foliating trees with the approximate dimension of 6m high and 4m wide to the south of Point 1, the wind conditions at this point will become acceptable for their intended use. These treatments are shown in Figure 7a.

The initial results for Point 10, which is located within the private garden area on the western edge of the site, indicate that the point is subjected to strong westerly and southerly winds. These wind conditions exceed the safety limit criterion of 23m/s for an annual maximum peak wind speed and the short exposure criterion of 5.5 m/s for weekly maximum GEM wind speeds. With the addition of several densely foliating trees with the approximate dimension of 6m high and 4m wide along the boundary of the proposed development to the west of Point 10, the wind conditions at this point will become acceptable for their intended use. These treatments are shown in Figure 7a.

5.2 Level 3 Podium

The Study Points:

Points 11 and 13 to 20 were used to monitor the wind conditions on the level 3 podium (Points 12 and 21 will be discussed in section 5.3). The locations of these points are also shown in Figure 6b.

Applicable Criteria:

The appropriate wind comfort criterion for limited use of the recreation area in the central outdoor space is the short exposure criterion of 5.5 m/s for weekly maximum GEM wind speeds. The northern and southern sides of the level 3 podium that adjoin the private balconies are compared against the comfortable walking criterion of 7.5m/s for GEM wind speeds. The private balconies were compared to the safety limit criterion of 23 m/s for annual maximum peak wind speeds.

In addition to the above criteria, all podium rooftop terrace areas should satisfy the Melbourne (1978) safety limit criterion of 23 m/s for annual maximum peak wind speeds.

Results and Recommendations:

The results indicate that the wind conditions for Points 11, 14, 19 and 20 located in short exposure area will to be acceptable for their intended use without the need for any treatments.

The wind conditions at Points 16, 17 and 18 exceed the short exposure criterion of 5.5 m/s for weekly maximum GEM wind speeds. With the addition of trees on the podium as shown in Figure 7b the wind conditions at these points become acceptable for their intended use. The wind conditions at Points 13 and 15 only marginally exceed the short exposure criterion of 5.5 m/s for weekly maximum GEM wind speeds for south easterly winds. With the addition of the trees indicated in the architectural drawings it is expected that the wind conditions at Points 13 and 15 will be acceptable for their intended use. It is expected that the wind conditions on the podium level can be further enhanced with the inclusion of the planter boxes shown on the architectural drawings. These treatments are shown in Figure 7b.

5.3 Private Balconies and Terraces

The Study Points:

Points 12 and 21 to 30 were used to monitor the wind conditions on the private balconies on the proposed development. Points 12 and 21 represent the wind conditions on podium balconies. Points 22 to 30 represent the wind conditions on upper levels of the balconies. The locations of these points are also shown in Figures 6b and 6c.

Applicable Criteria:

The appropriate wind comfort criterion for these areas is the Melbourne (1978) safety limit criterion of 23 m/s for annual maximum peak wind speeds.

Results and Recommendations:

The results indicate that the wind conditions at Points 12 and 22 to 28, located in the safety limit area of Figures 6b and 6c, will be acceptable for their intended use without the need for any treatments.

The wind conditions at Points 21, 29 and 30 exceed the safety limit criterion of 23 m/s for annual maximum peak wind speeds. These conditions mainly occurred for winds from the south. Treatments were tested on Points 29 and 30, with Point 30 representing Point 21. Initially 1.2m high impermeable balustrades were tested on the southerly aspect of these balconies, however these were found to have a negligible effect. With the addition of full height screens on the southerly side of the south facing balconies of southern tower, wind conditions will be suitable for their intended use. These full height screens may be replaced with full height operable louvers, whereby in the event of an extreme wind they could be closed. The treatments are shown in Figure 7c.

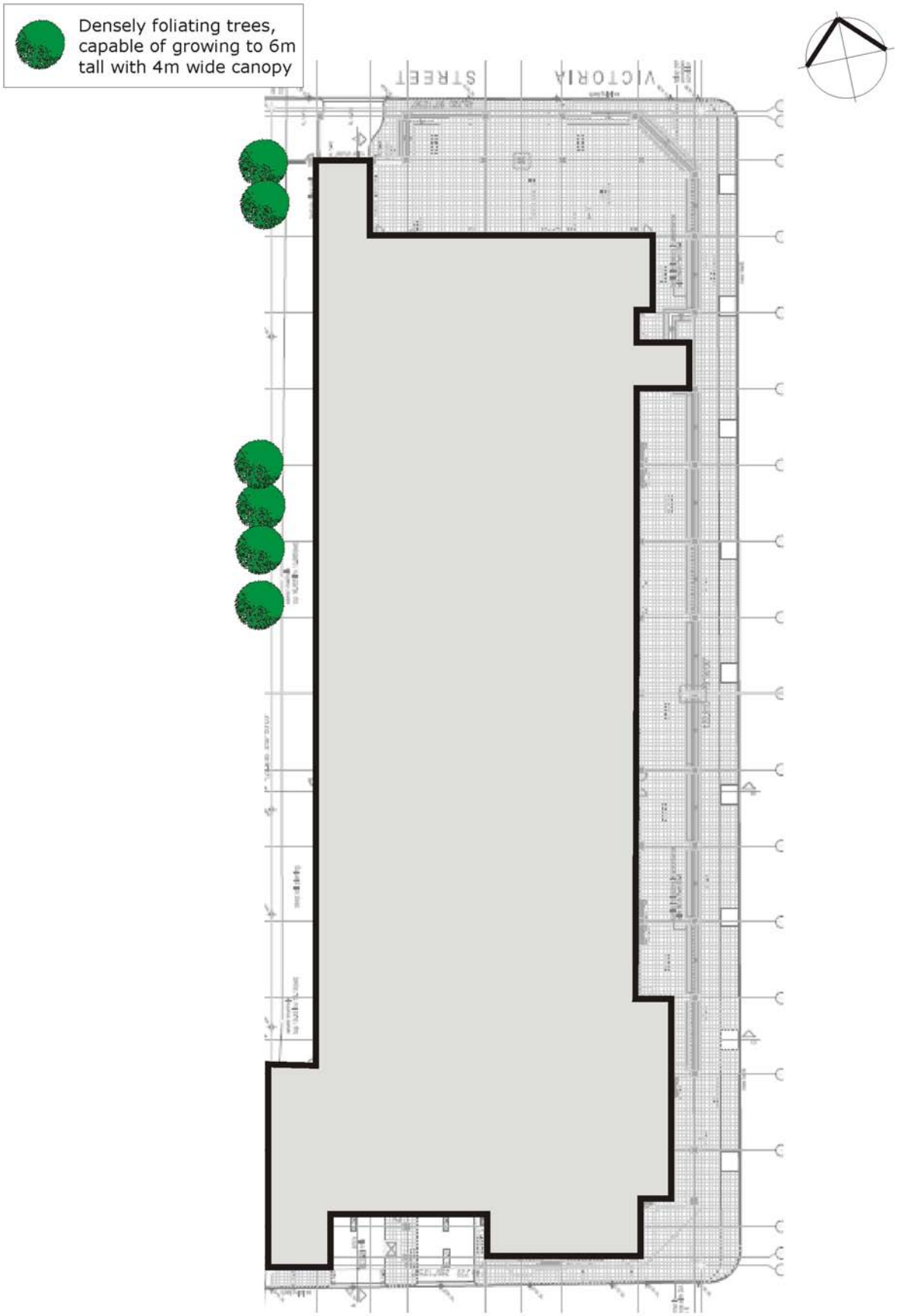

Figure 7a: Recommended Treatments for the Ground Level Areas of the Site

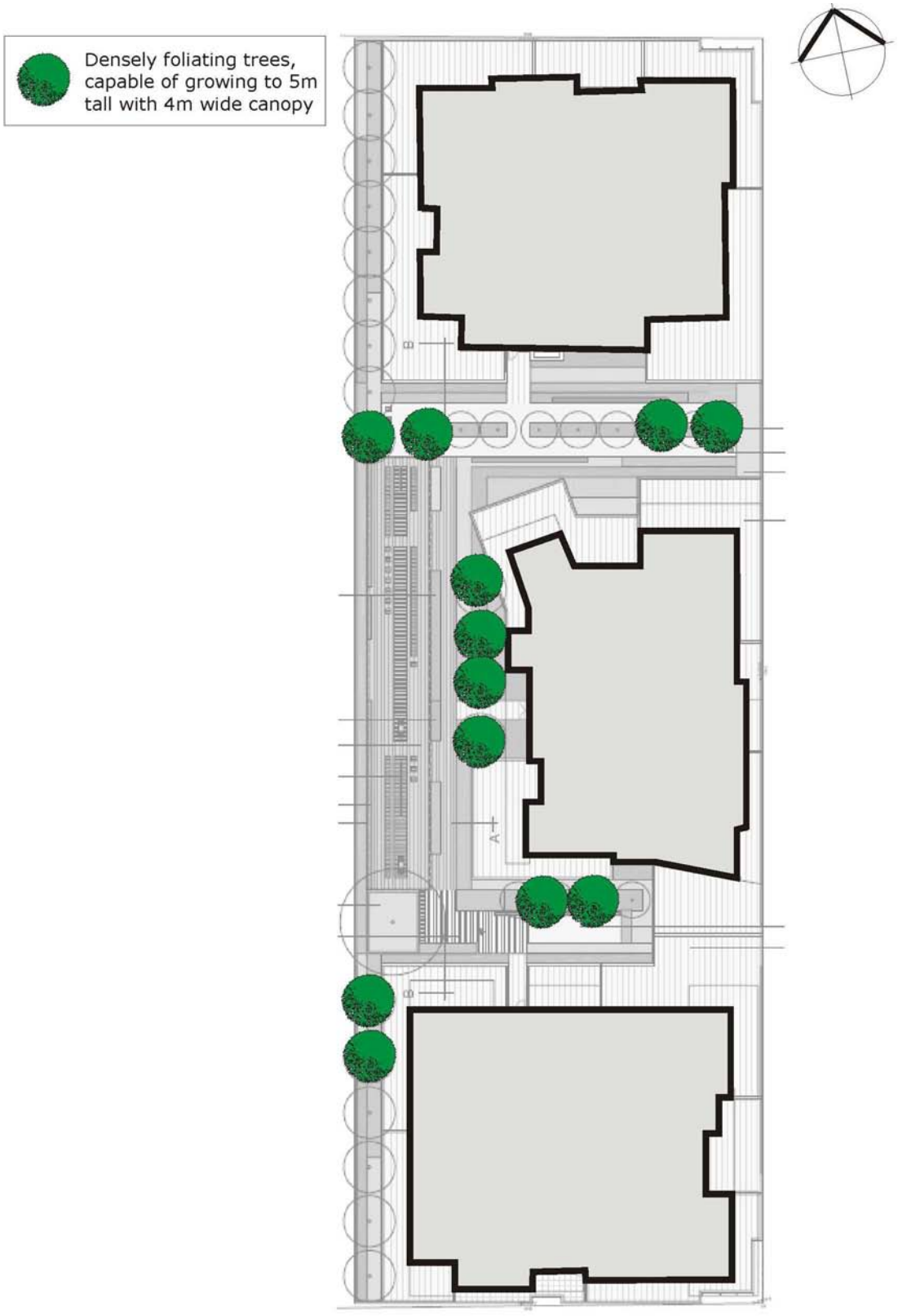

Figure 7b: Recommended Treatments for the Level 3 Podium

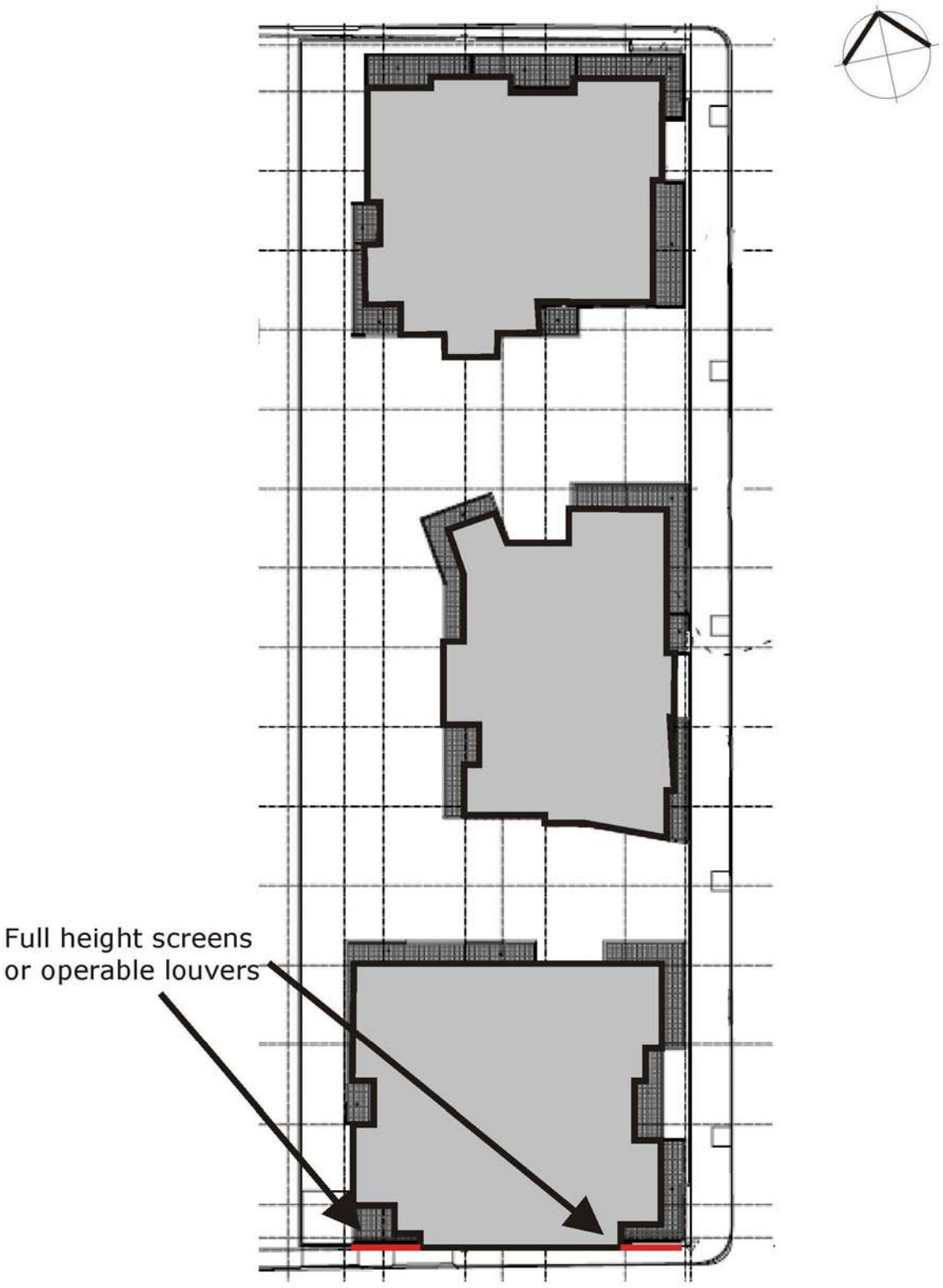

Figure 7c: Recommended Treatments for the Typical Tower Levels

6.0 Conclusion

A wind tunnel study has been carried out to investigate the wind environment effects pertaining to the development at 1-17 Elsie Street, located between Victoria, Elsie and George Streets, Burwood.

The results of the study indicate that wind conditions for most of the site are acceptable for their intended uses. Treatments have been recommended in this report for several areas of the development to mitigate against adverse wind effects. The treatments recommended in this report are summarised as follows:

- The addition of two densely foliating trees (capable of growing to approximately 6m tall with a 4m wide canopy) at ground level near the north-western corner of the site.

- The addition of several densely foliating trees (capable of growing to approximately 6m tall with a 4m wide canopy) at ground level on the western edge of site, within the private recreation area.

- The addition of several densely foliating trees (capable of growing to approximately 5m tall with a 4m wide canopy) on the Level 3 podium as indicated in Figure 7b.

- Impermeable full height screens or impermeable operable louvers on the southern edge of the south facing balconies of the southern tower.

Note that for the trees to be effective in mitigating against westerly, winds which are typically prevalent during the winter months for the Sydney region, evergreen should be used. The species of trees selected should also be of a densely foliating variety. Palm trees, for example, would not be effective in wind mitigation to ground level areas.

With the addition of the treatments listed above, all outdoor trafficable areas within and around the proposed development will be acceptable for their intended use.

References

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Appendix A

Wind Roses for the Sydney Region

Sydney Airport, 1939-2000

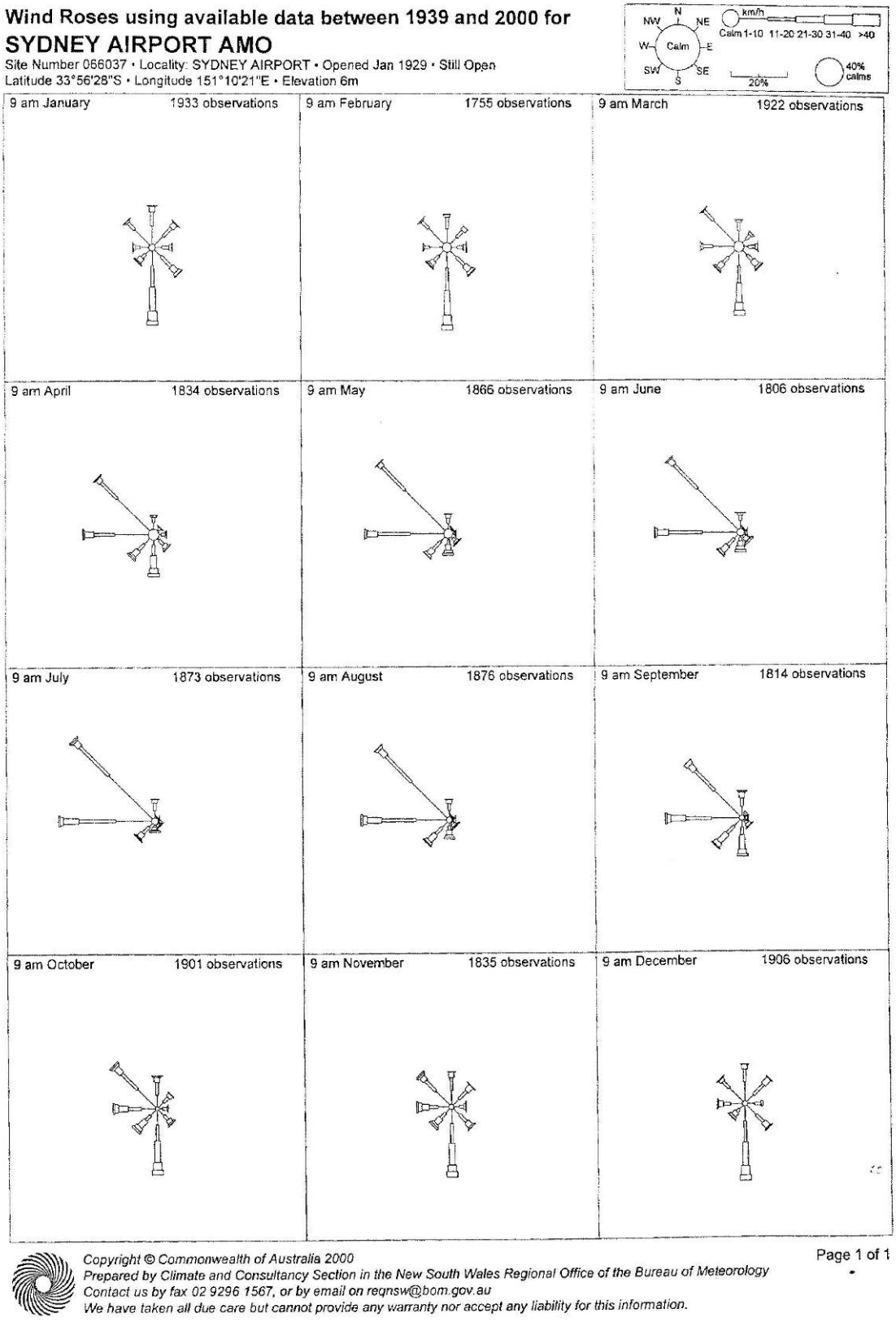


Figure A1: Monthly Wind Roses for the Sydney Region, at 9am (1939 to 2000)

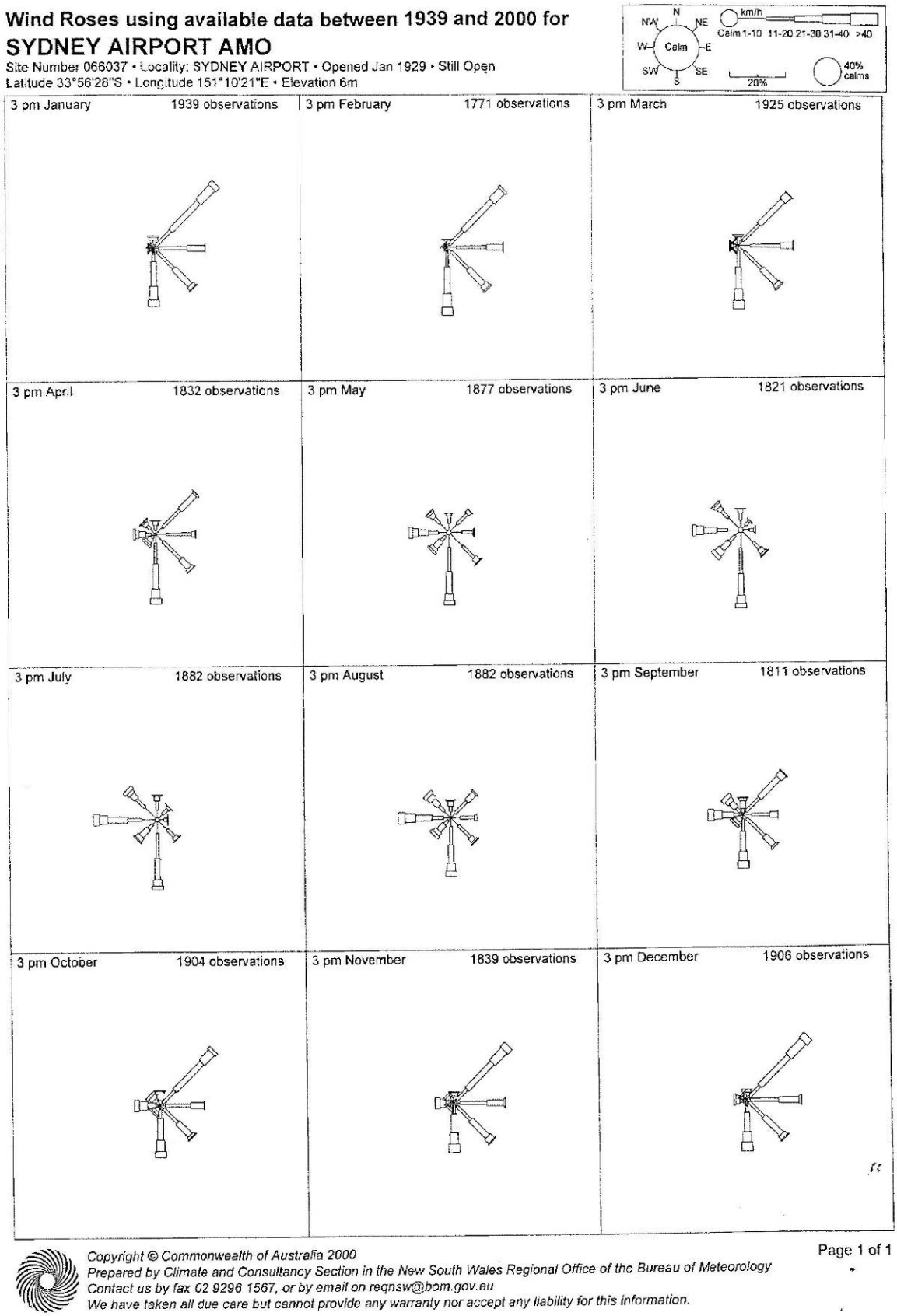


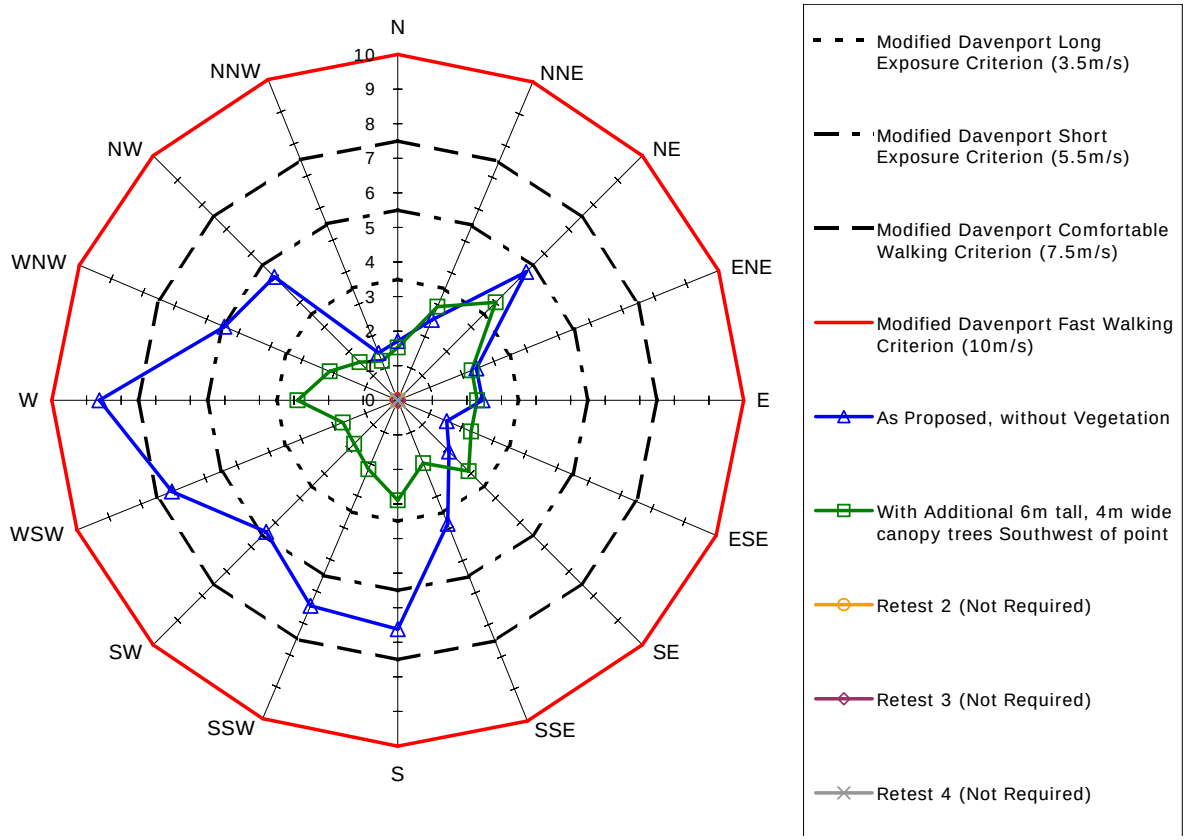
Figure A2: Monthly Wind Roses for the Sydney Region, at 3pm (1939 to 2000)

Appendix B

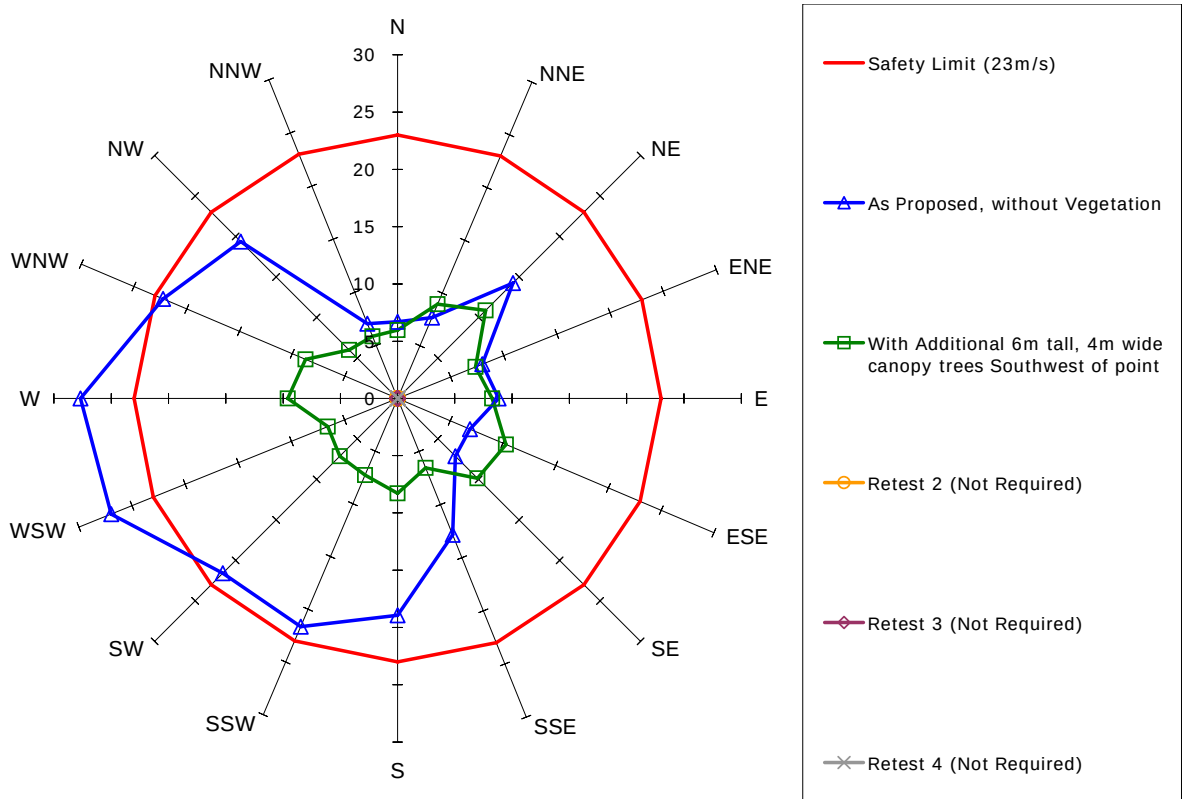
Plots of Wind Tunnel Results

Measured Wind Speeds at Point 01

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

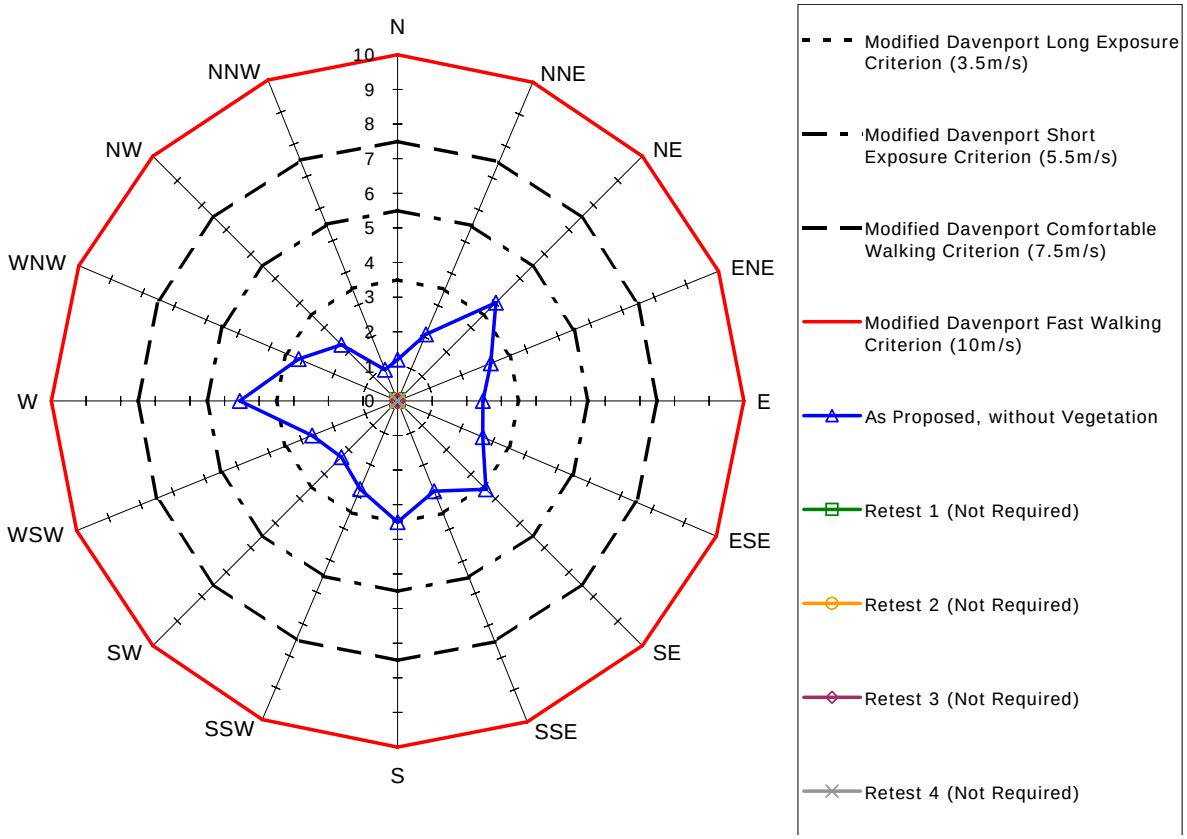


Annual Maximum Gust Wind Speeds (m/s)

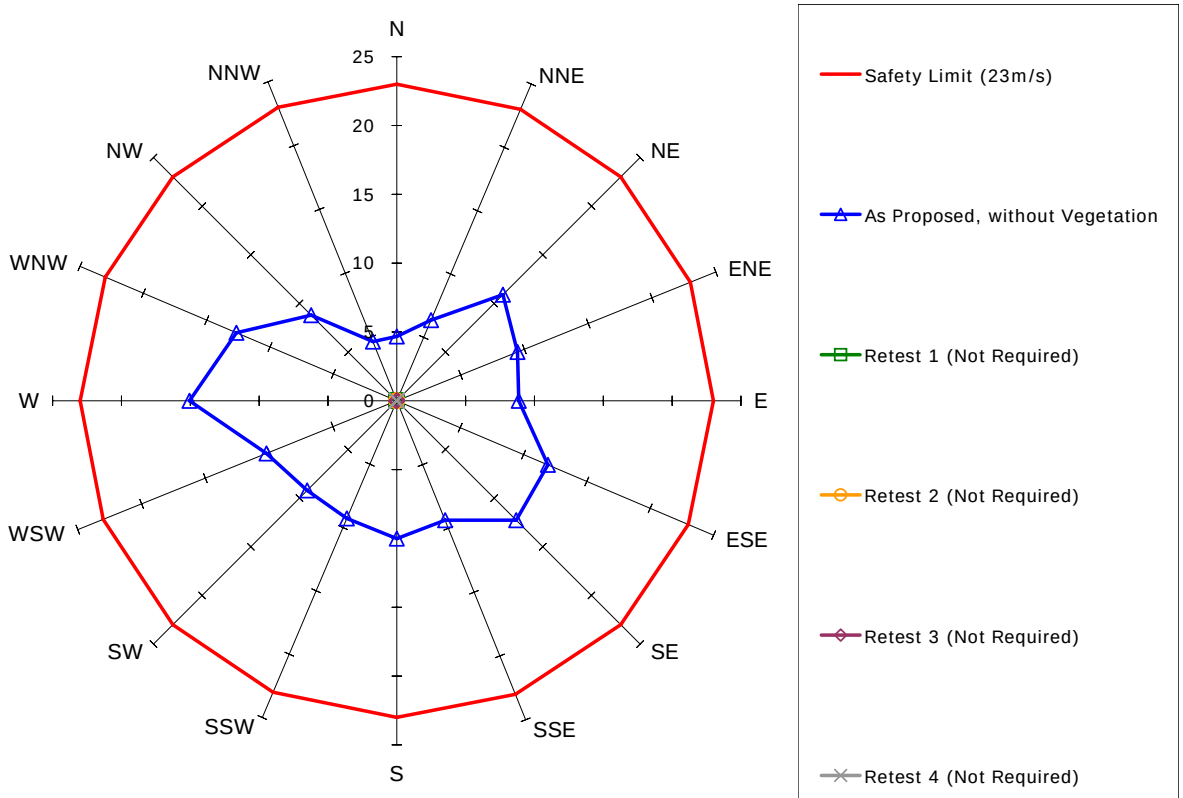


Measured Wind Speeds at Point 02

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

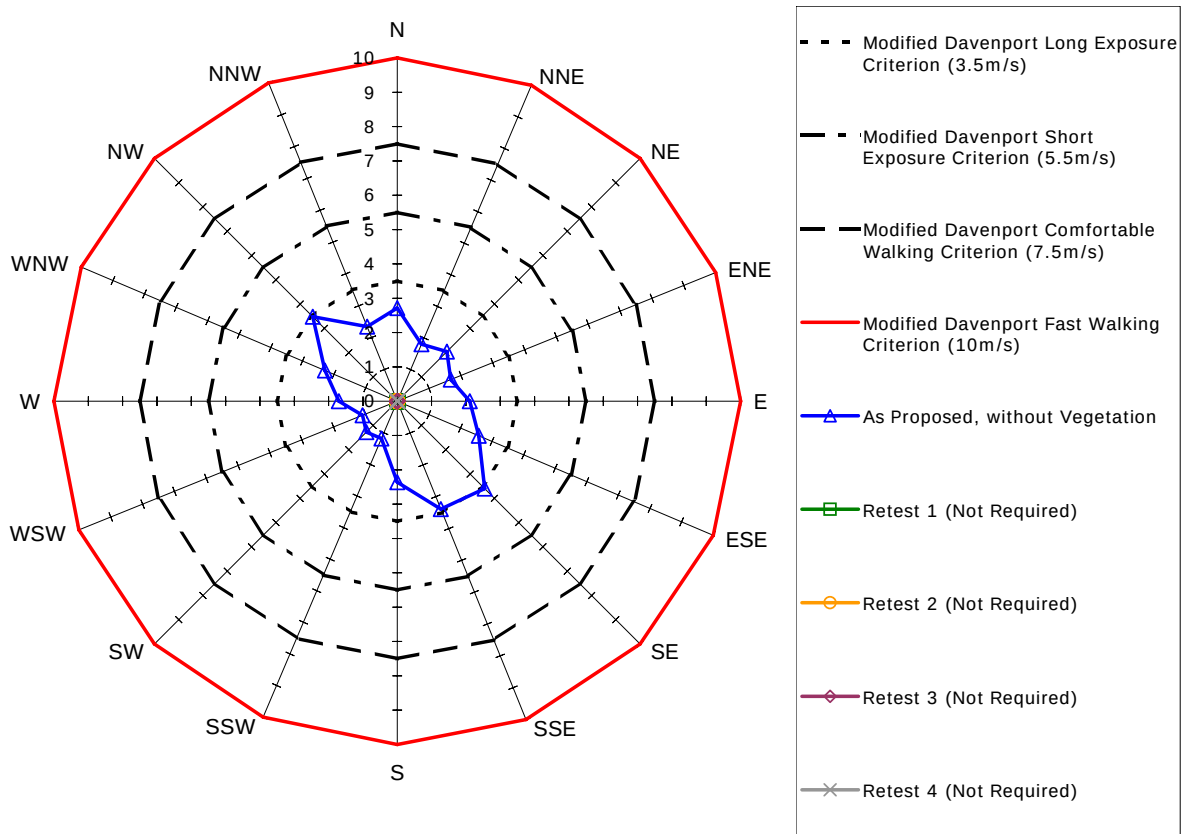


Annual Maximum Gust Wind Speeds (m/s)

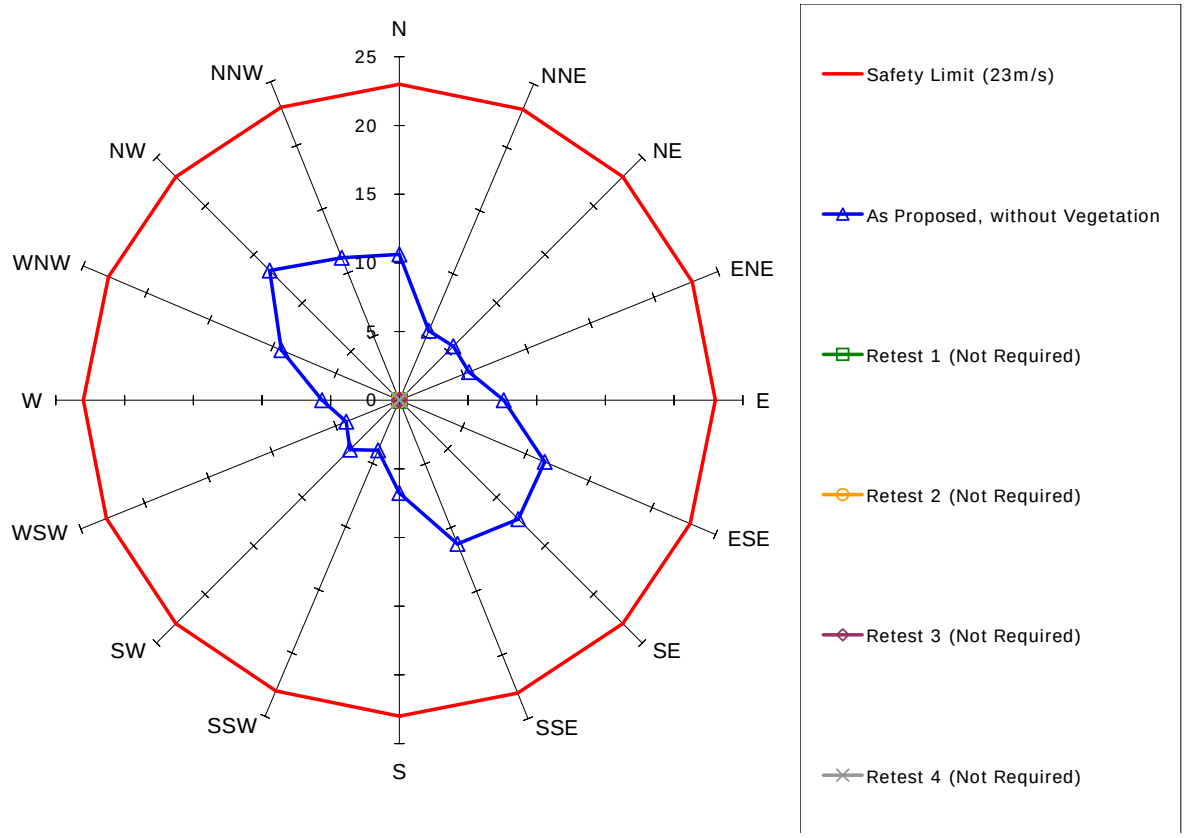


Measured Wind Speeds at Point 03

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

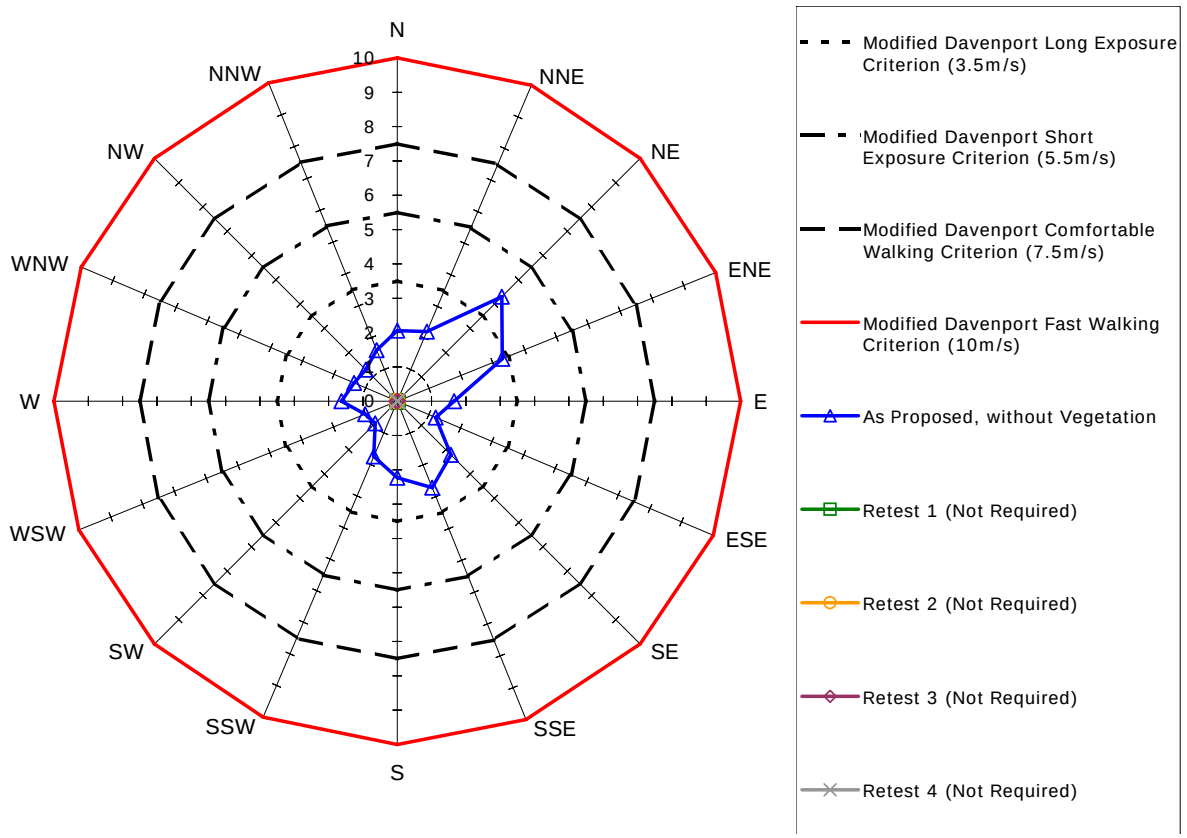


Annual Maximum Gust Wind Speeds (m/s)

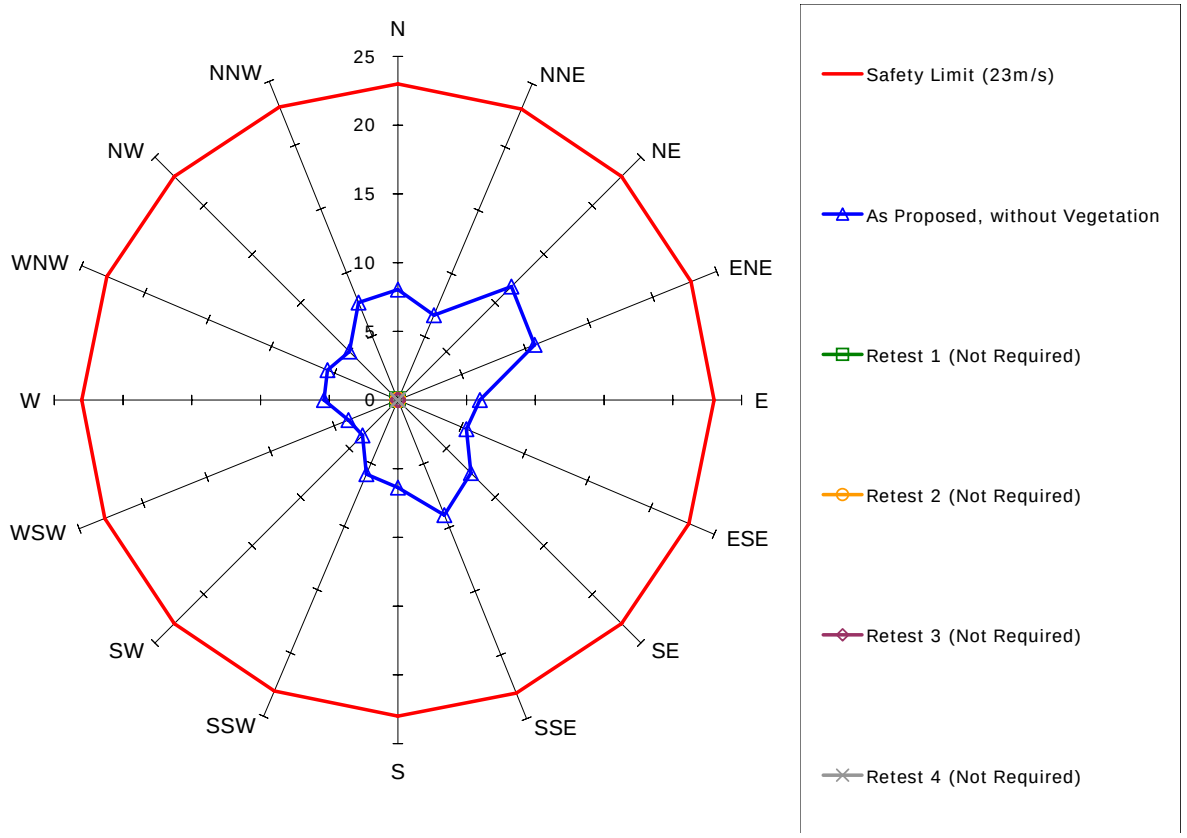


Measured Wind Speeds at Point 04

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

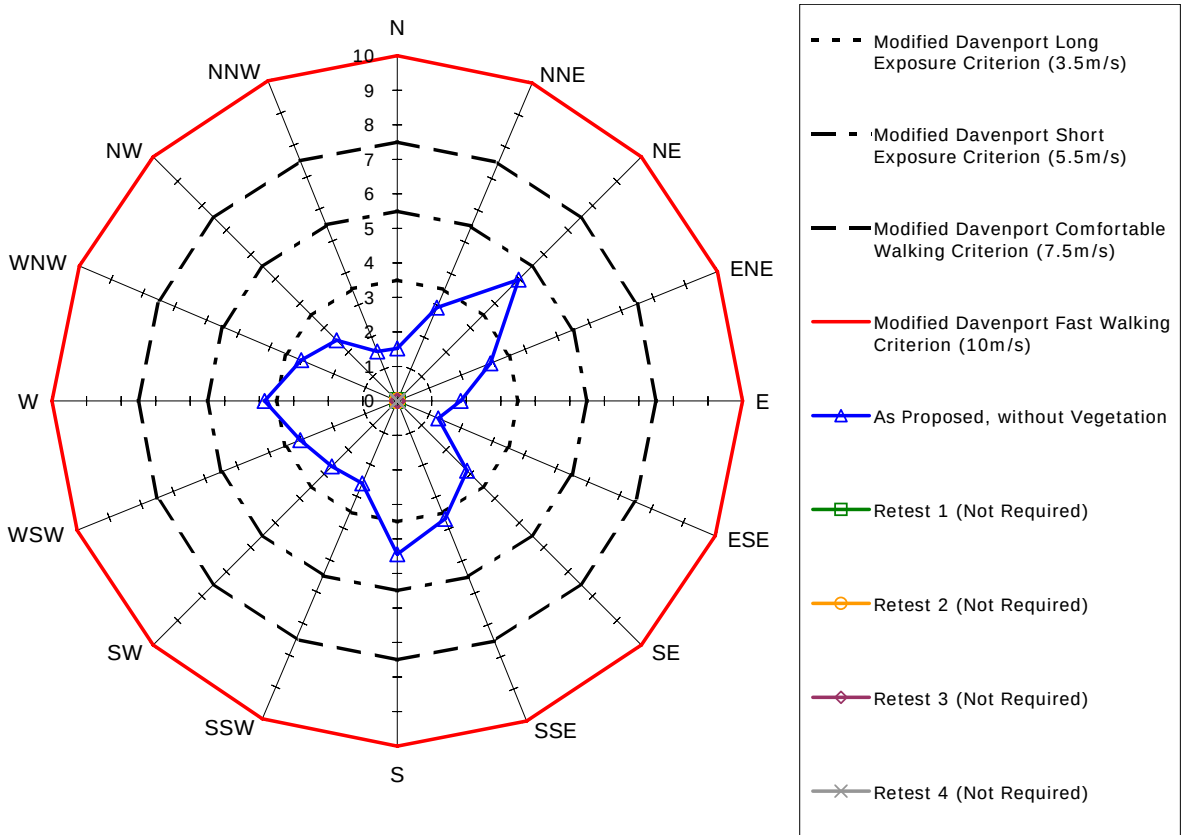


Annual Maximum Gust Wind Speeds (m/s)

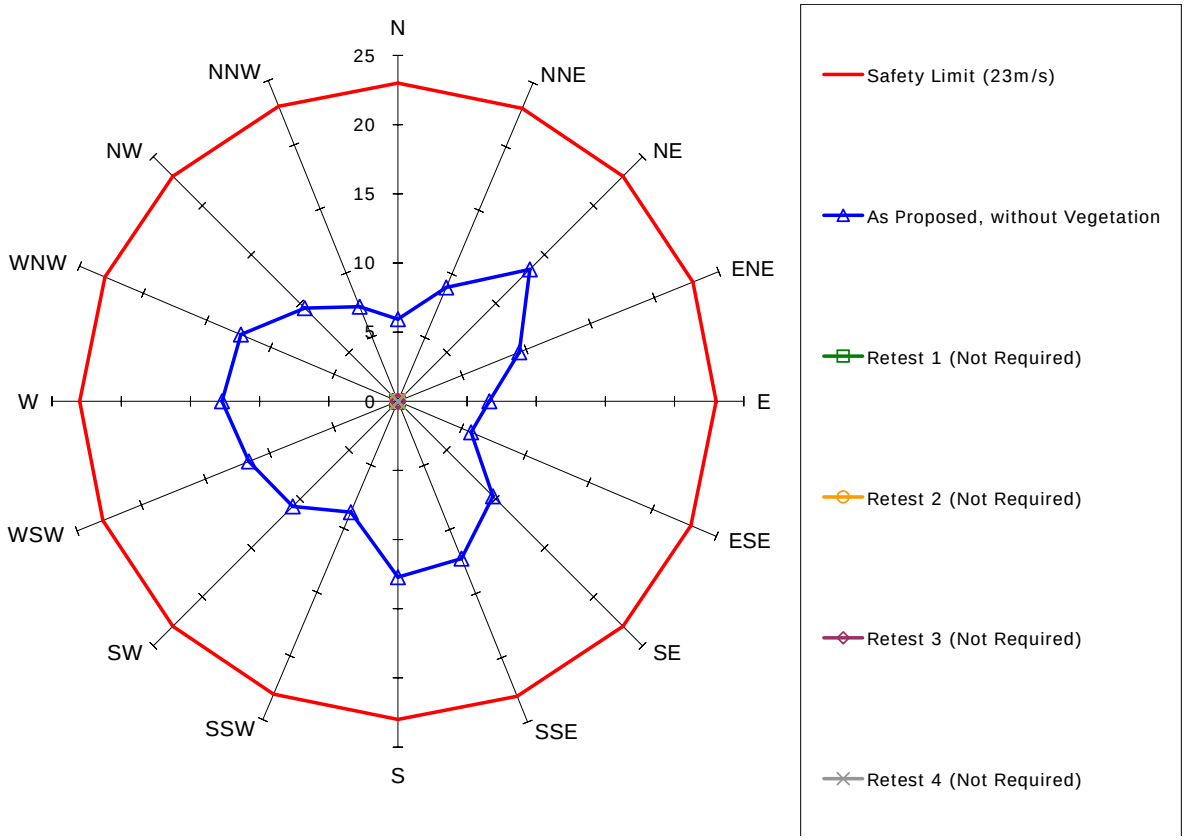


Measured Wind Speeds at Point 05

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

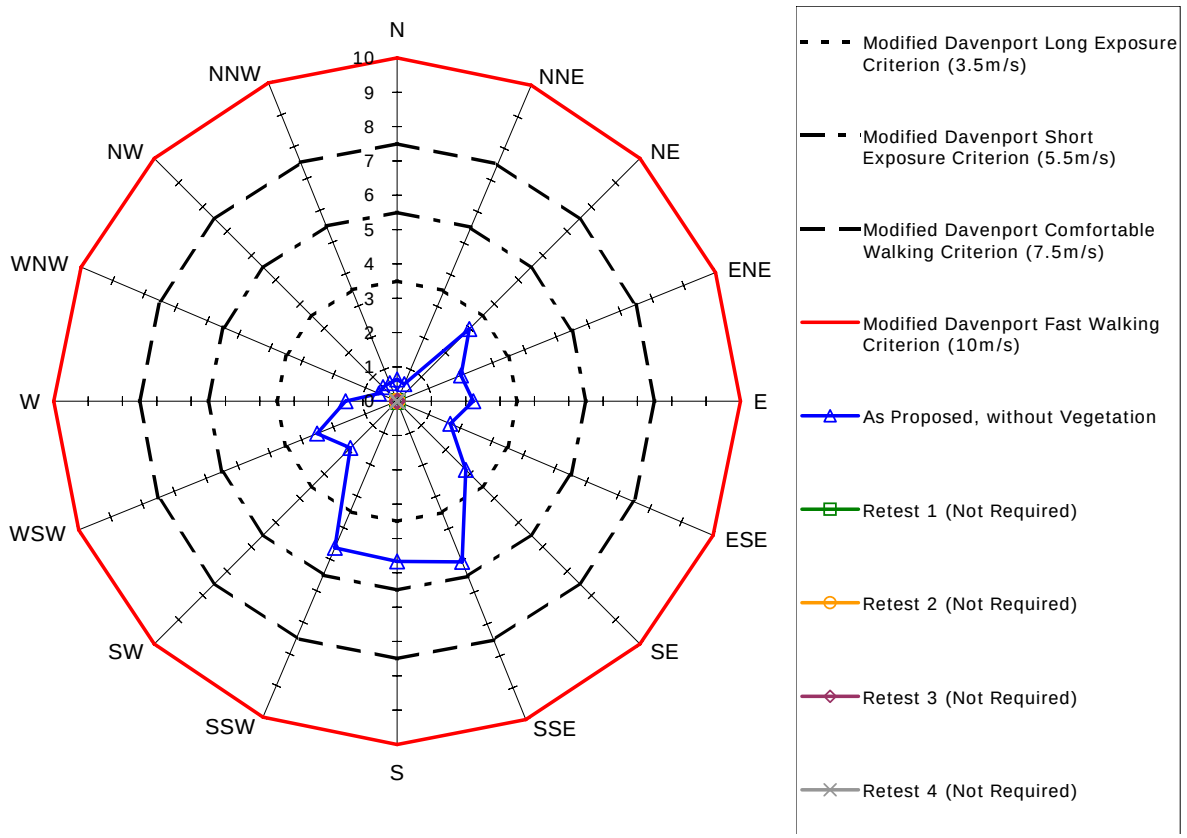


Annual Maximum Gust Wind Speeds (m/s)

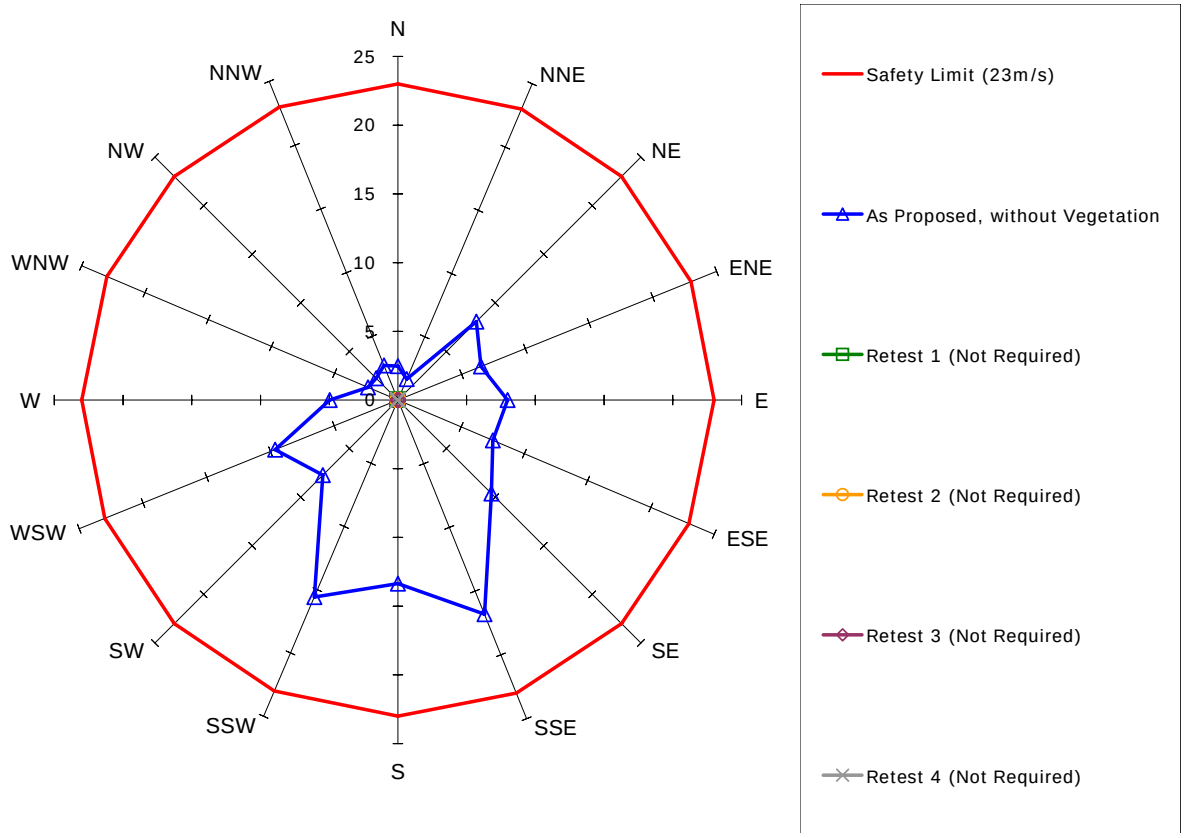


Measured Wind Speeds at Point 06

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

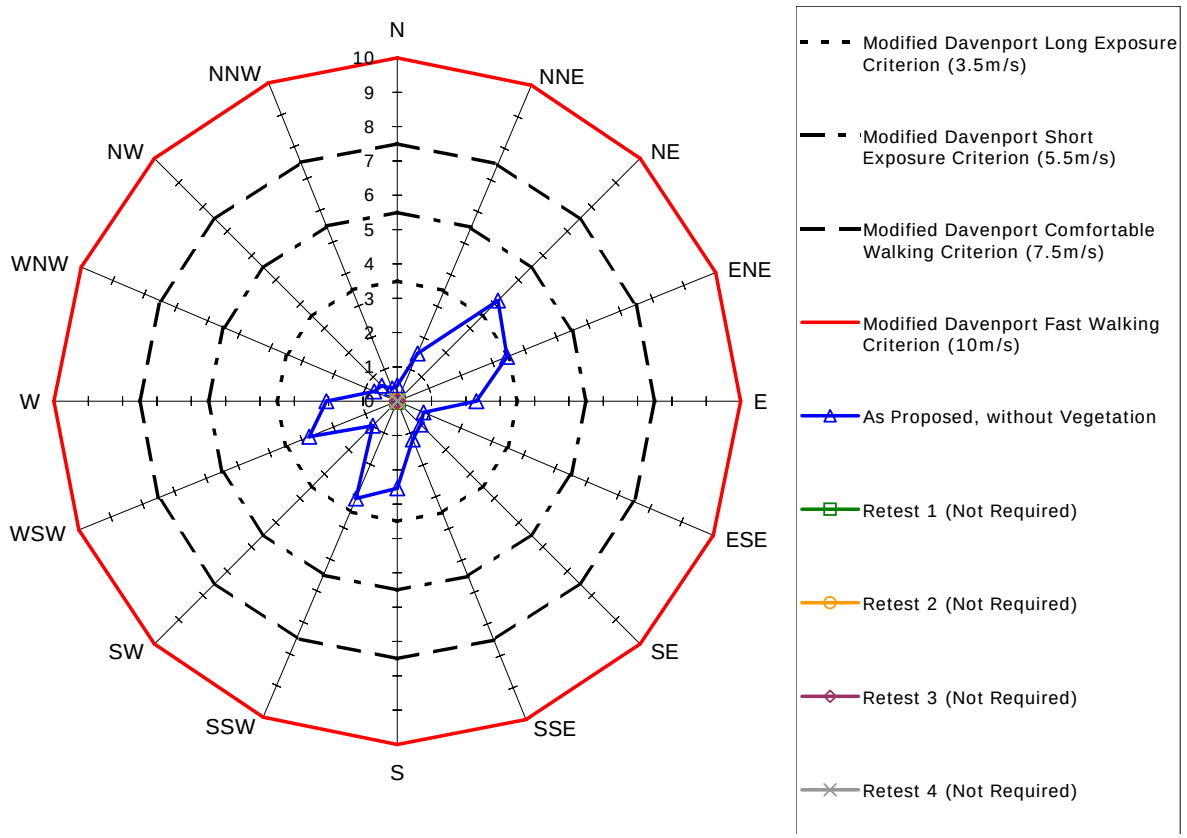


Annual Maximum Gust Wind Speeds (m/s)

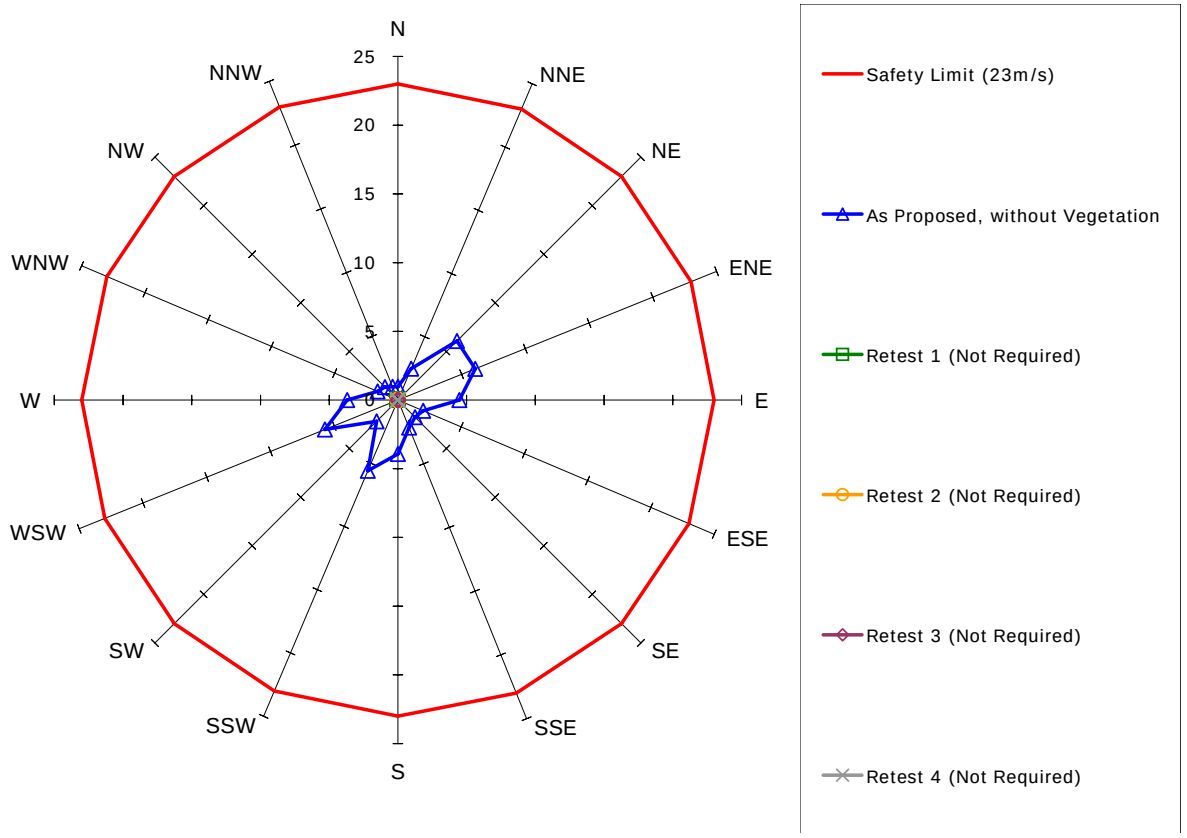


Measured Wind Speeds at Point 07

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

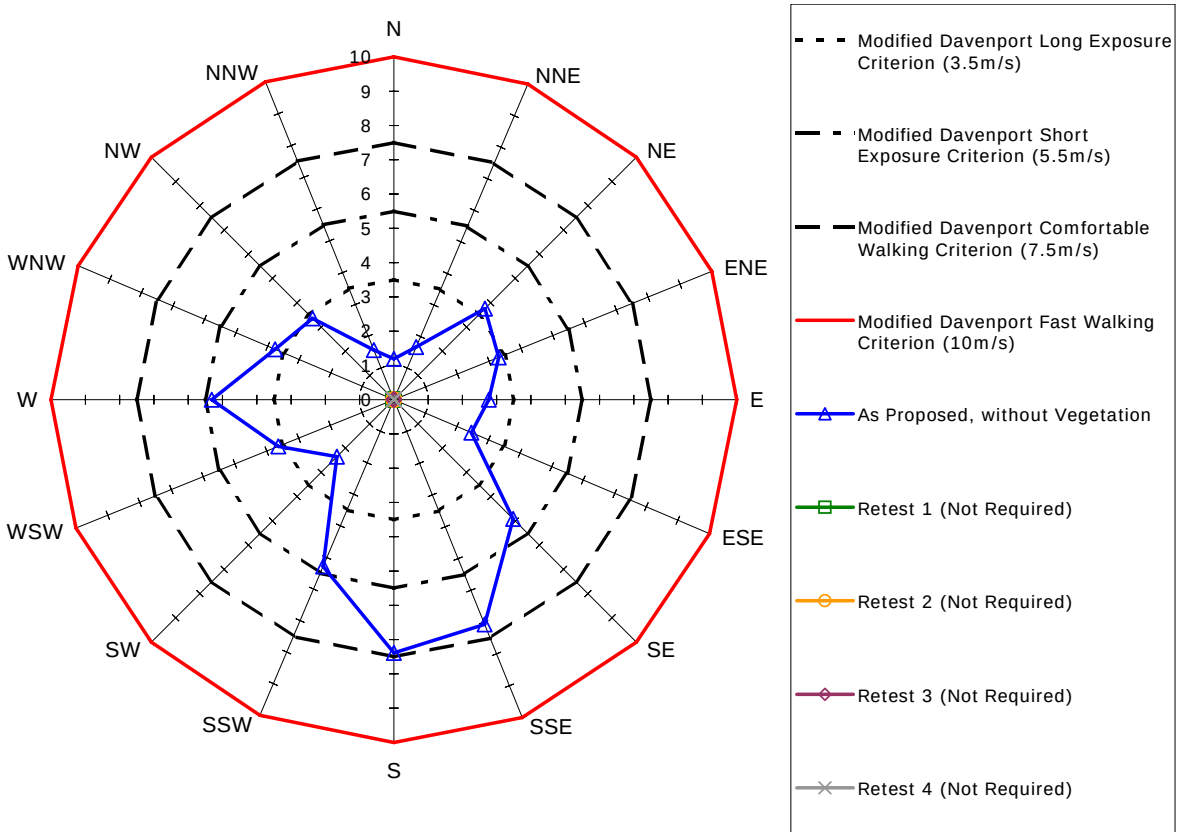


Annual Maximum Gust Wind Speeds (m/s)

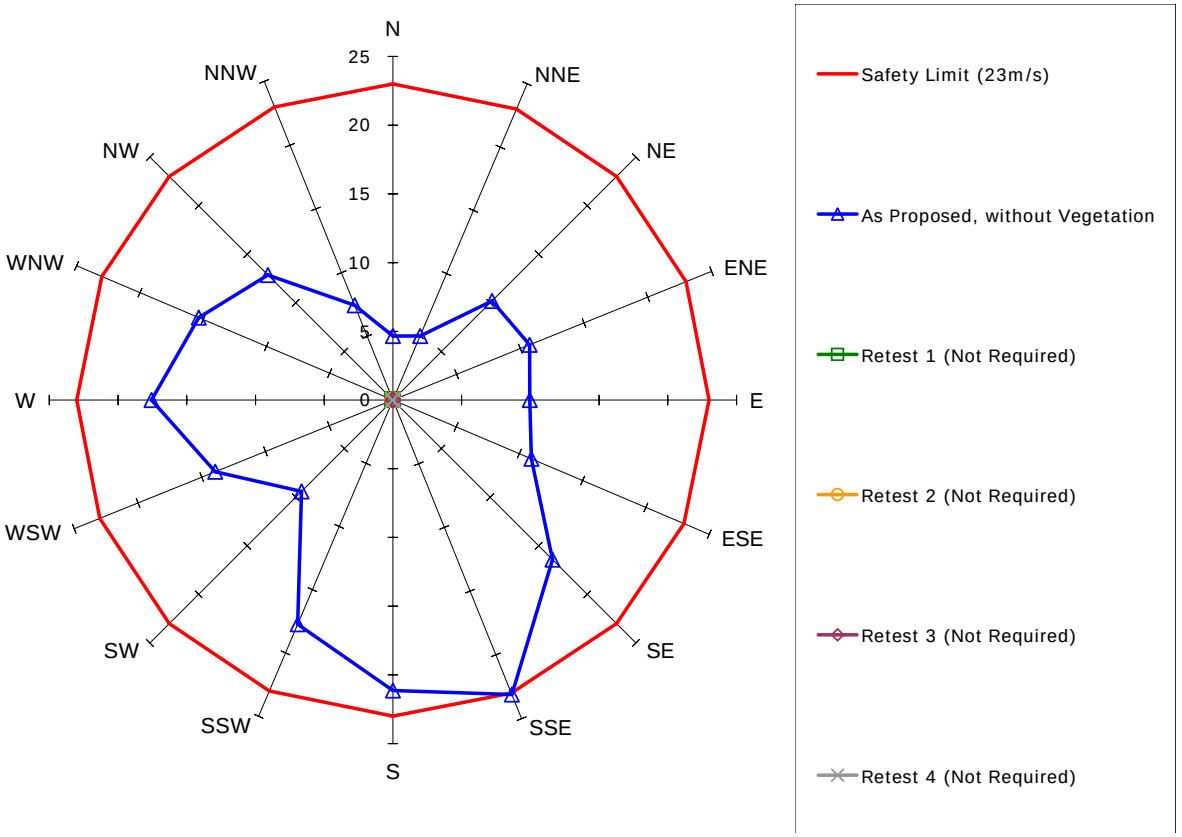


Measured Wind Speeds at Point 08

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

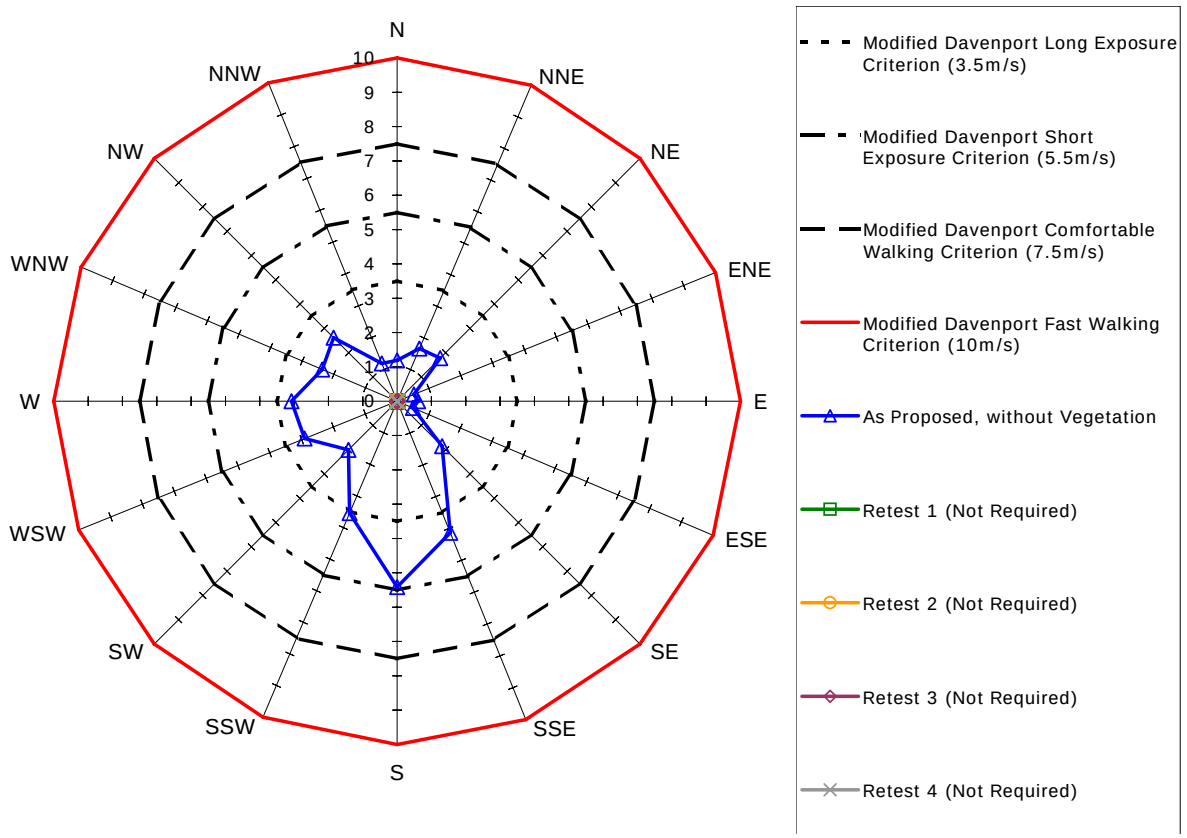


Annual Maximum Gust Wind Speeds (m/s)

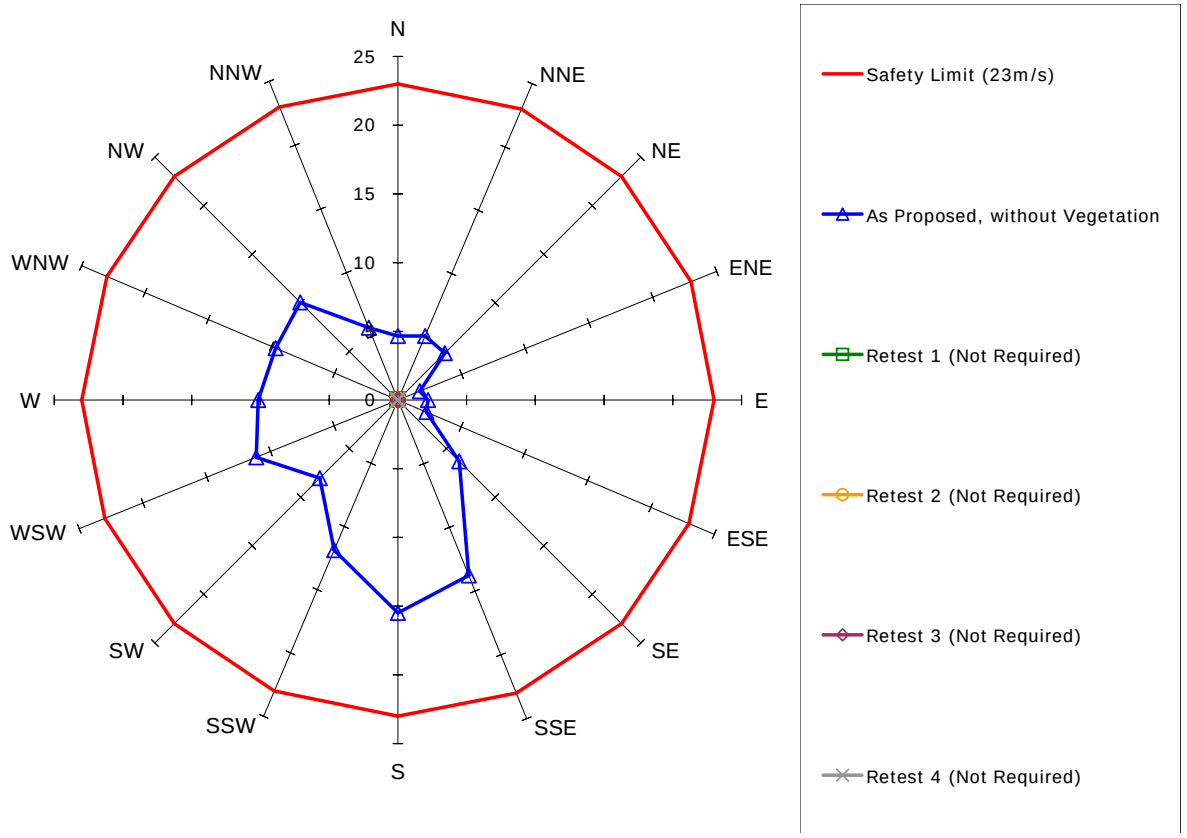


Measured Wind Speeds at Point 09

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

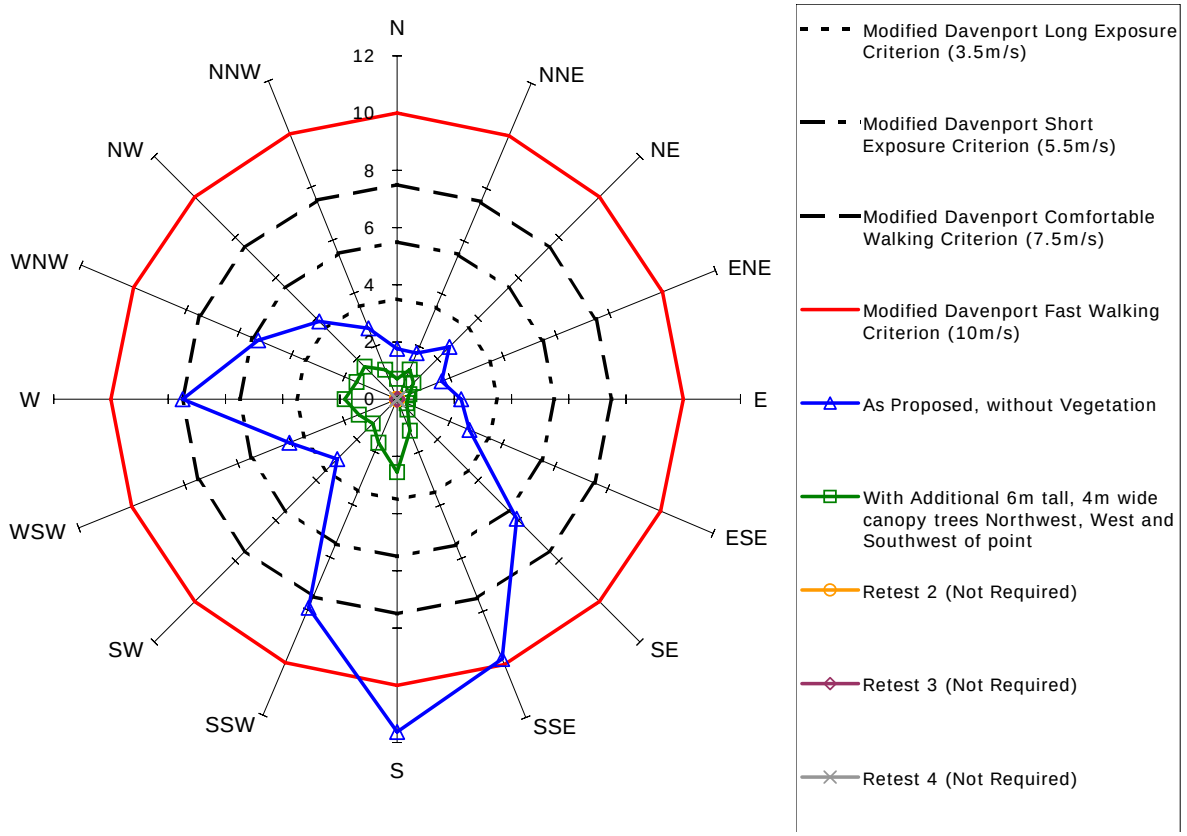


Annual Maximum Gust Wind Speeds (m/s)

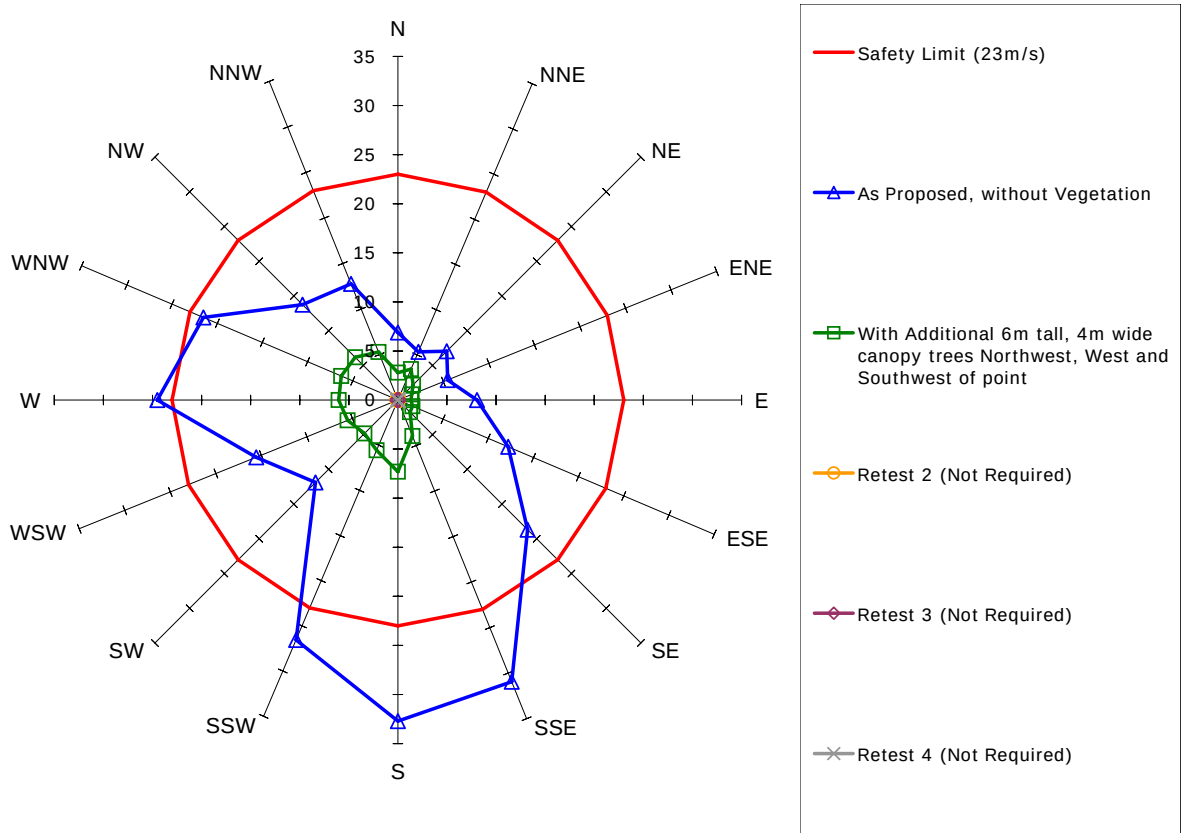


Measured Wind Speeds at Point 10

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

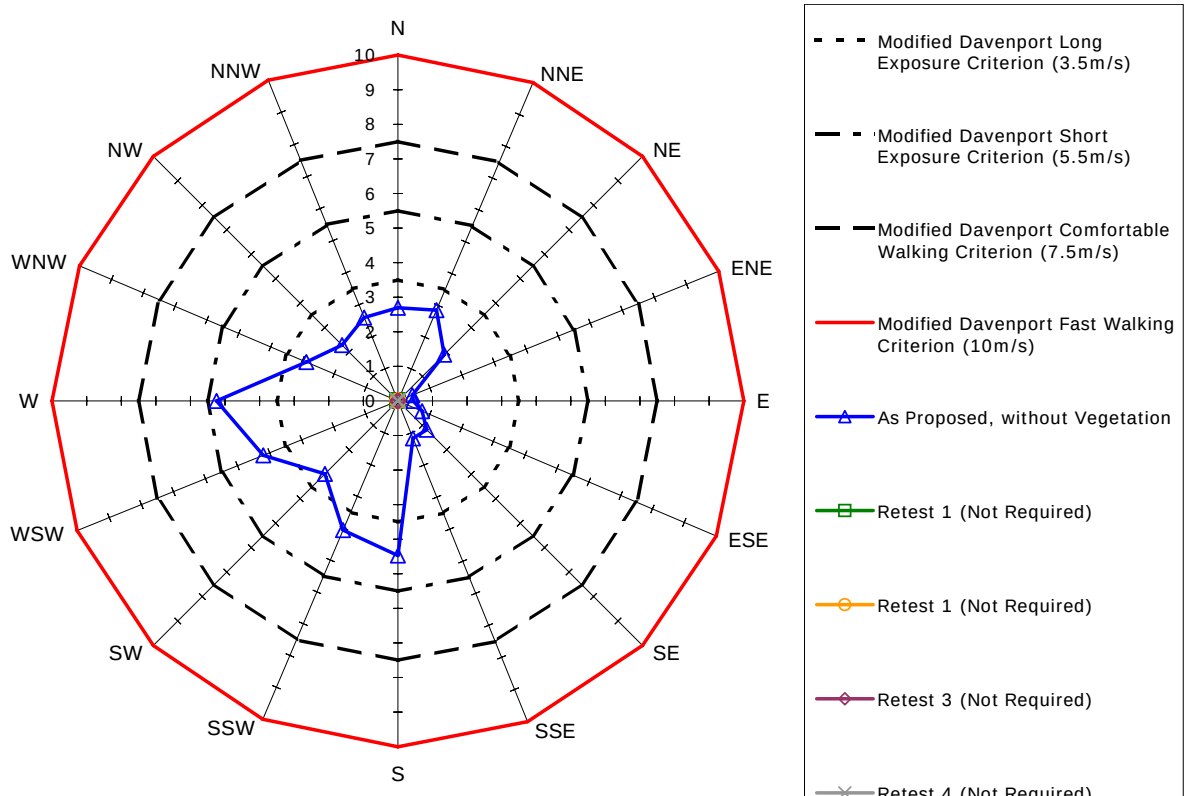


Annual Maximum Gust Wind Speeds (m/s)

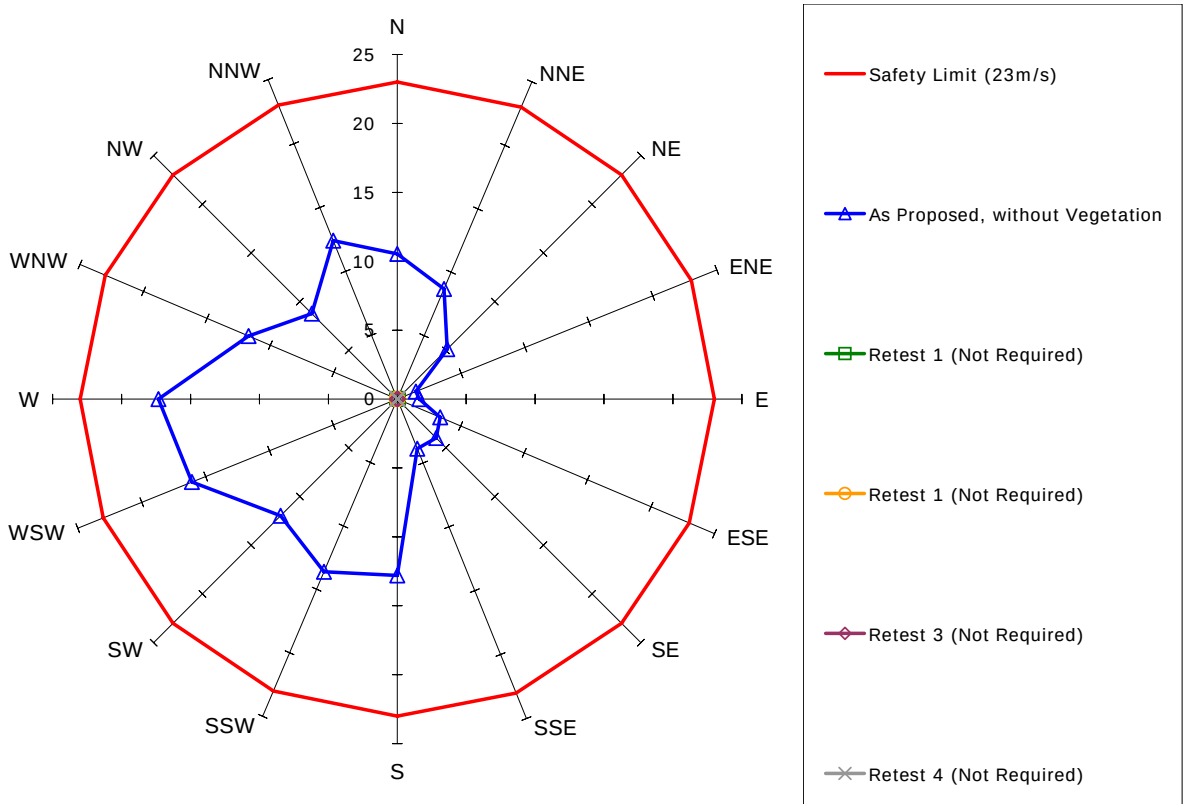


Measured Wind Speeds at Point 11

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

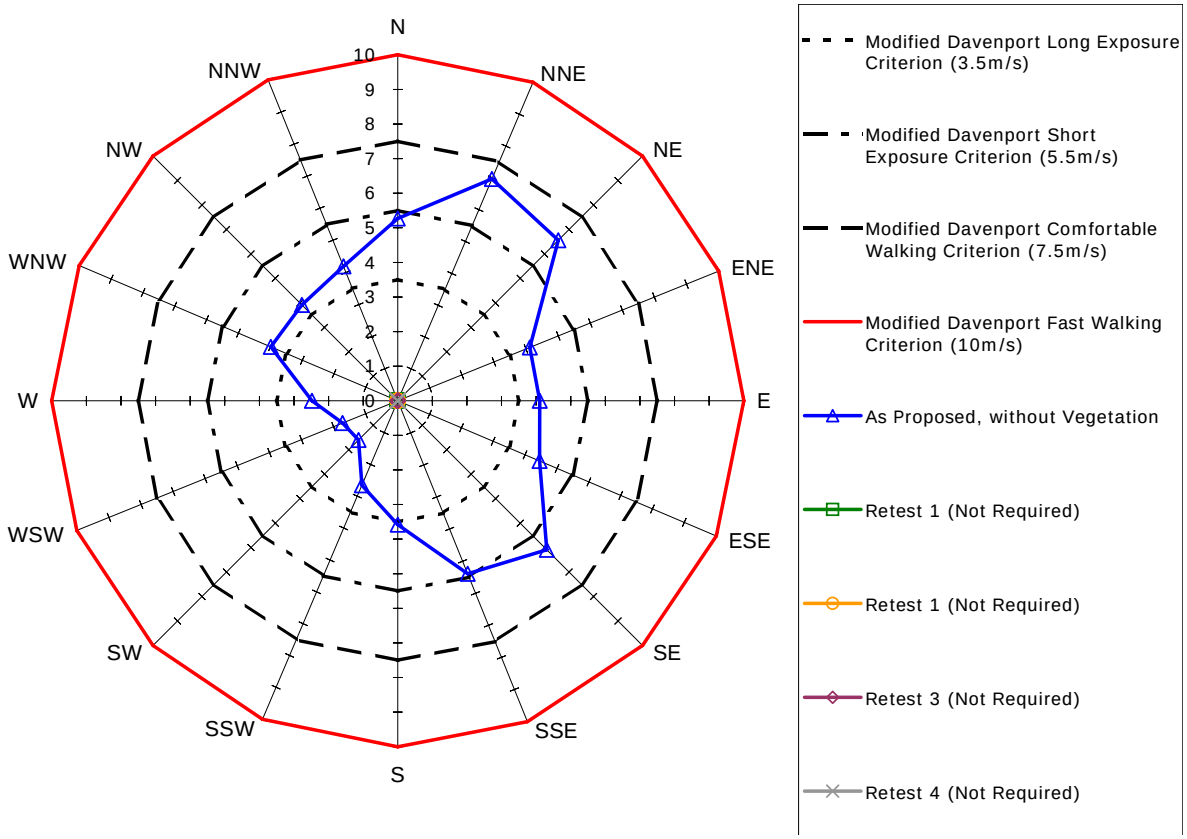


Annual Maximum Gust Wind Speeds (m/s)



Measured Wind Speeds at Point 12

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



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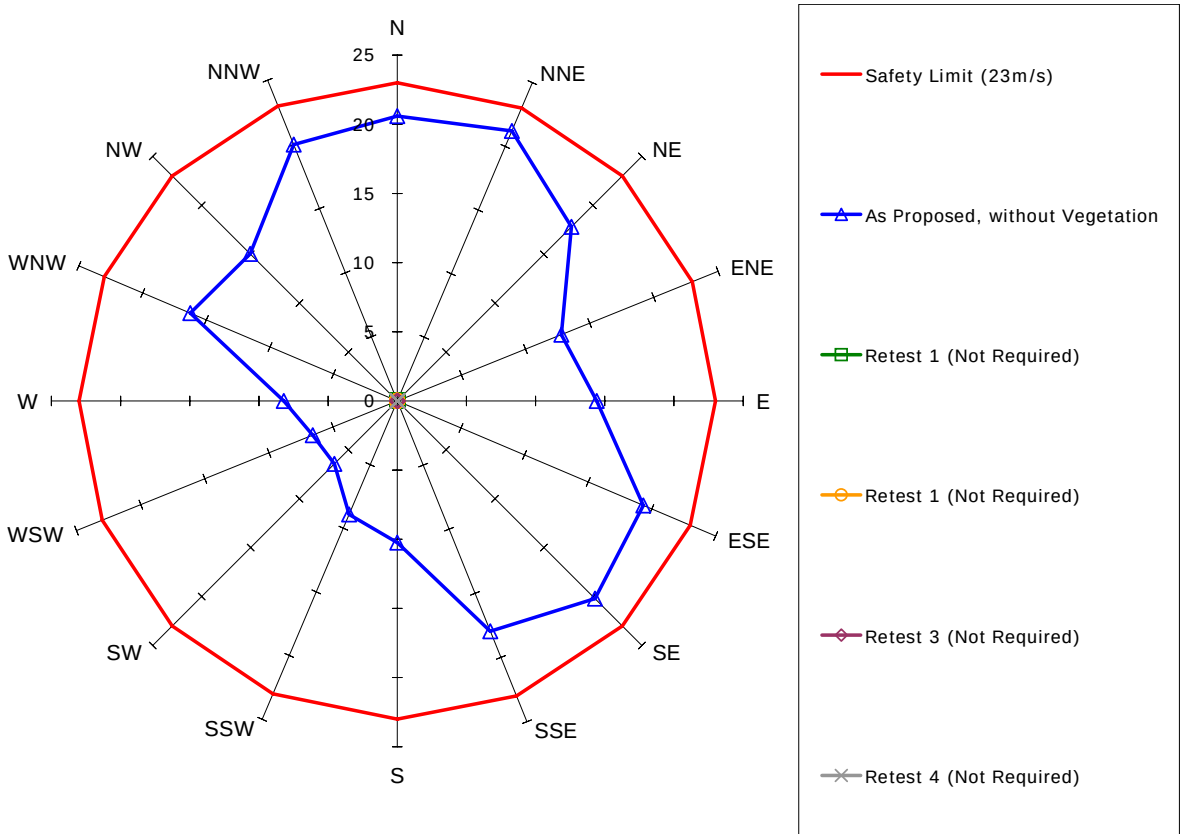
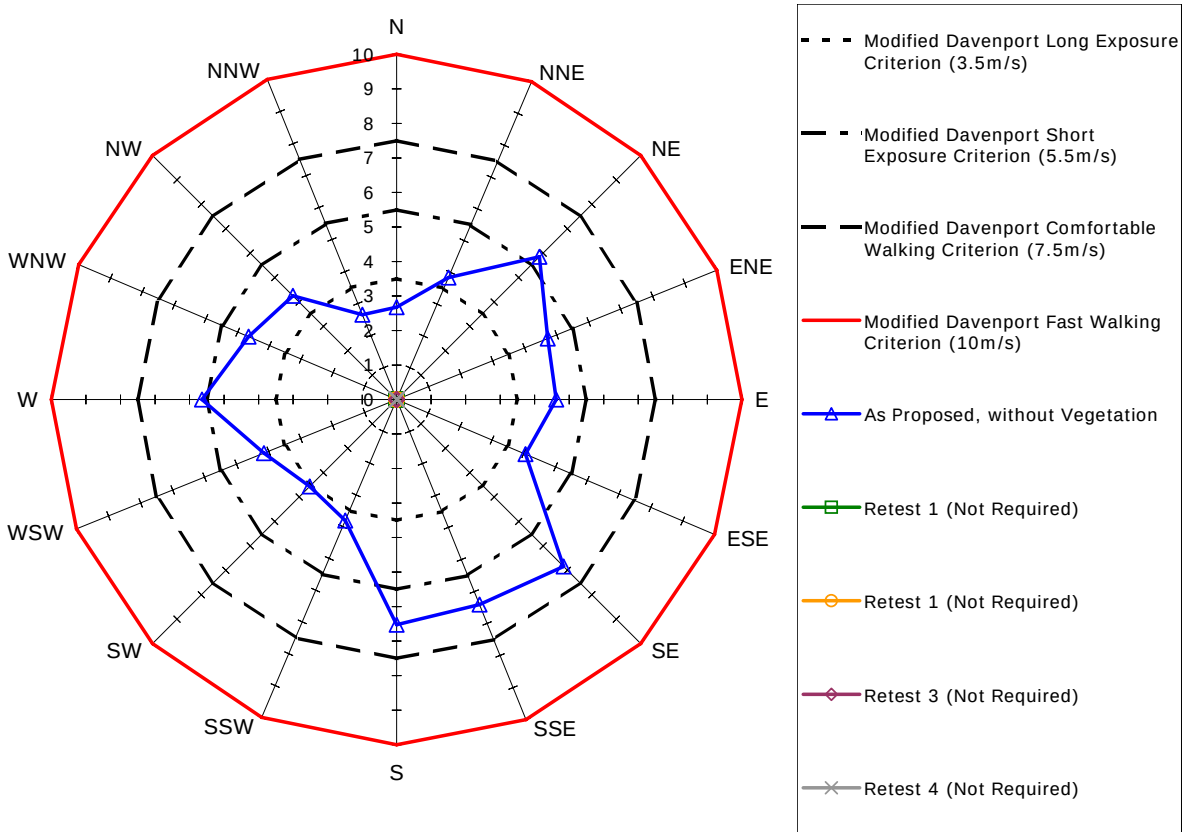


Measured Wind Speeds at Point 13

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



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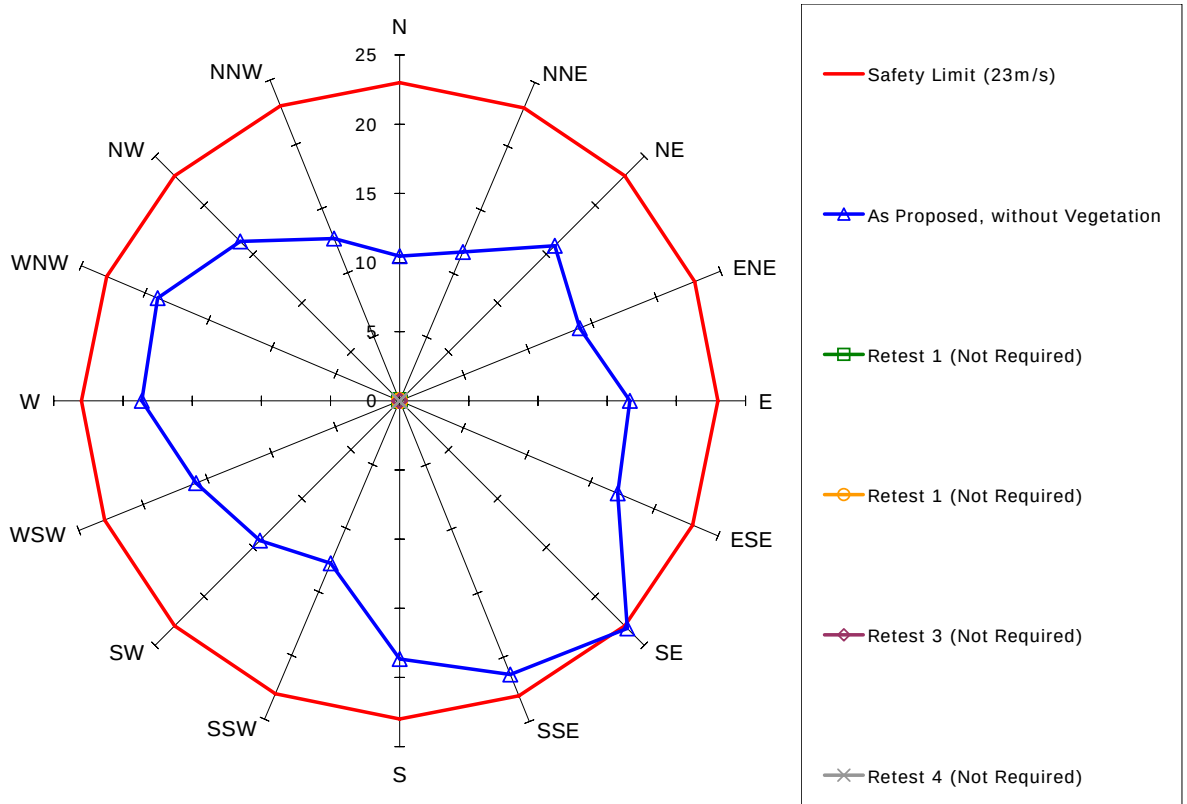
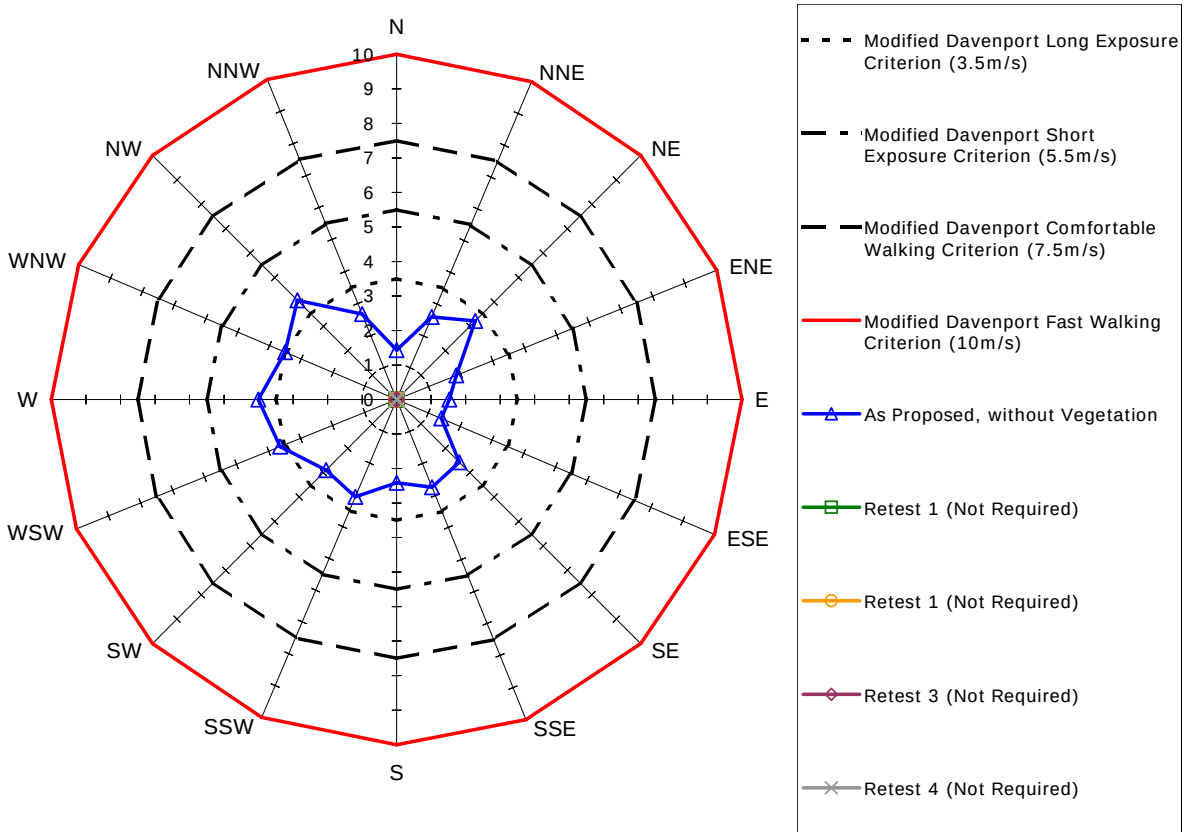
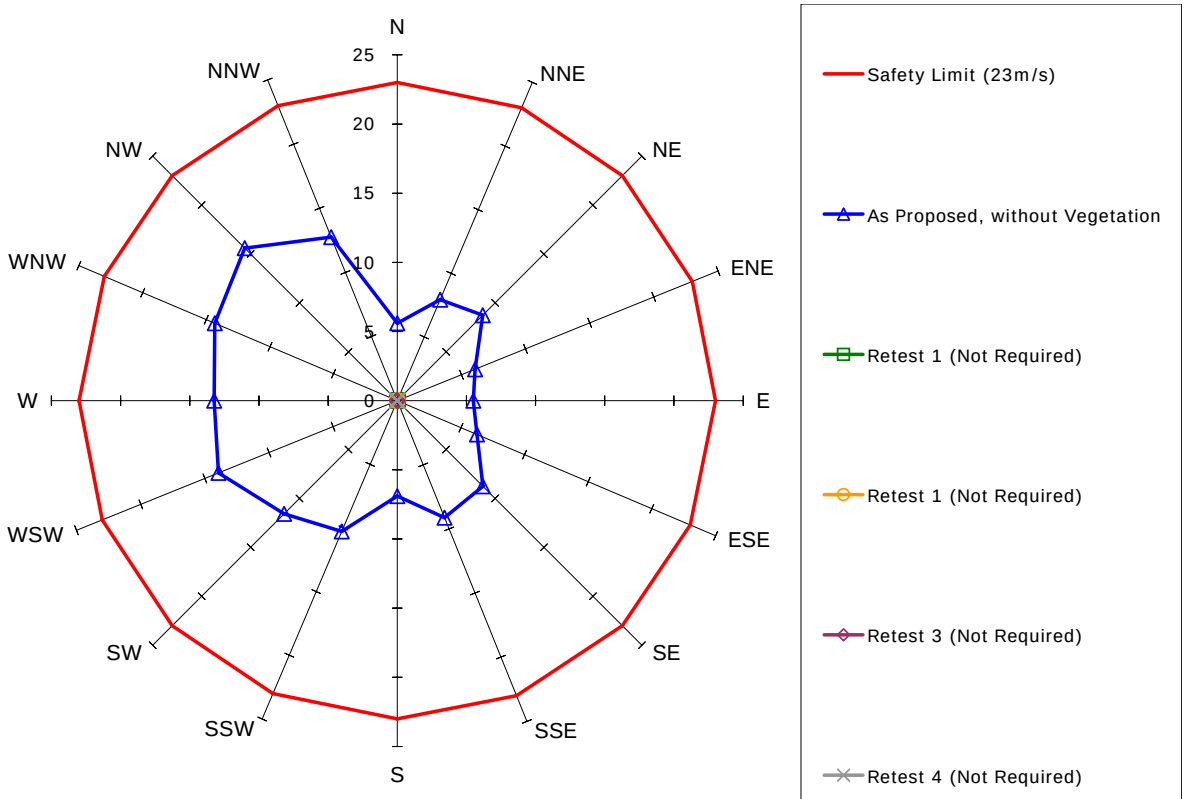


Measured Wind Speeds at Point 14

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

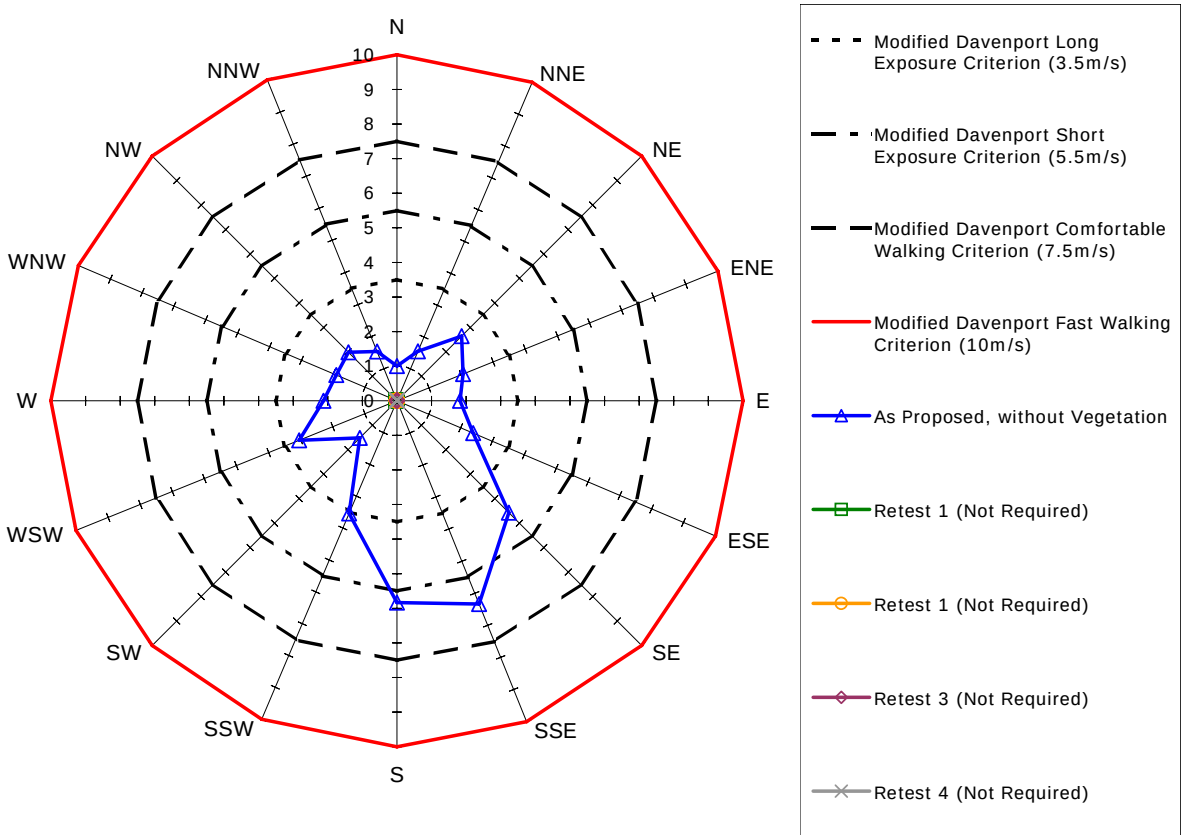


Annual Maximum Gust Wind Speeds (m/s)

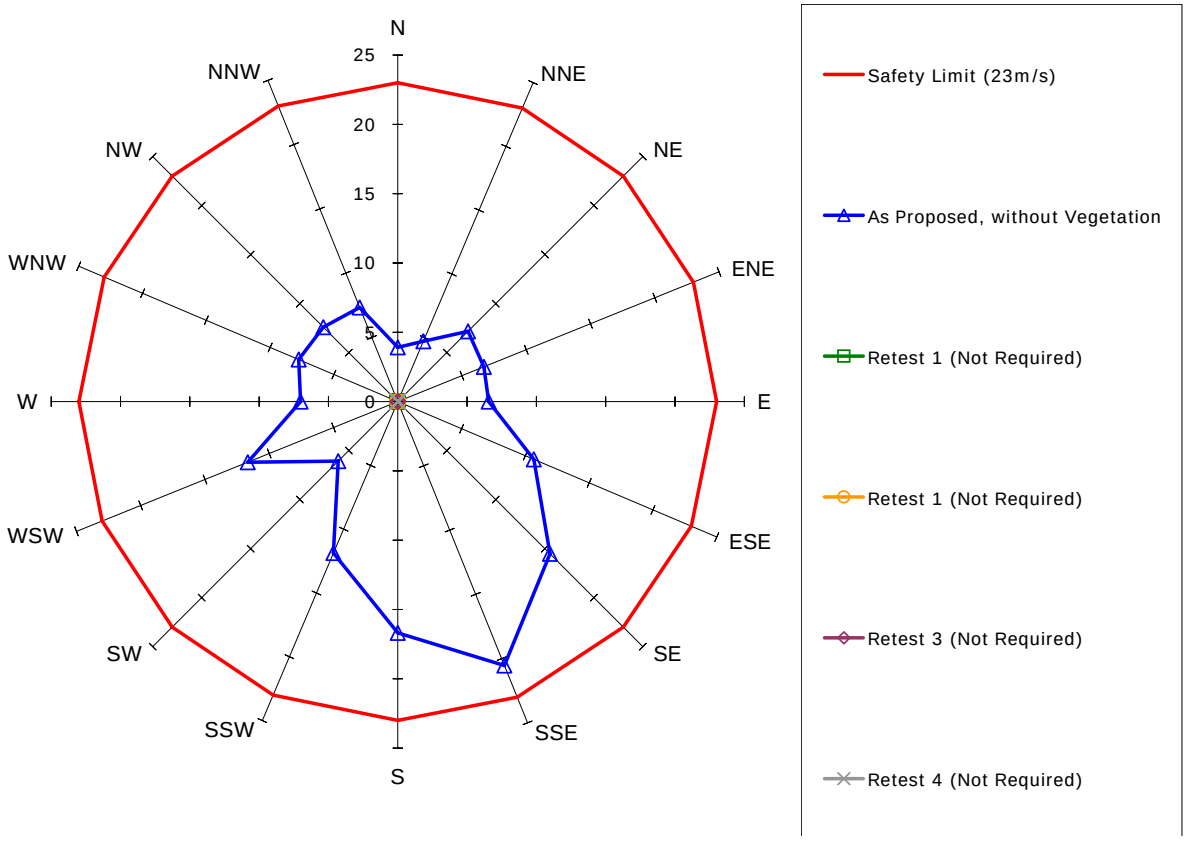


Measured Wind Speeds at Point 15

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

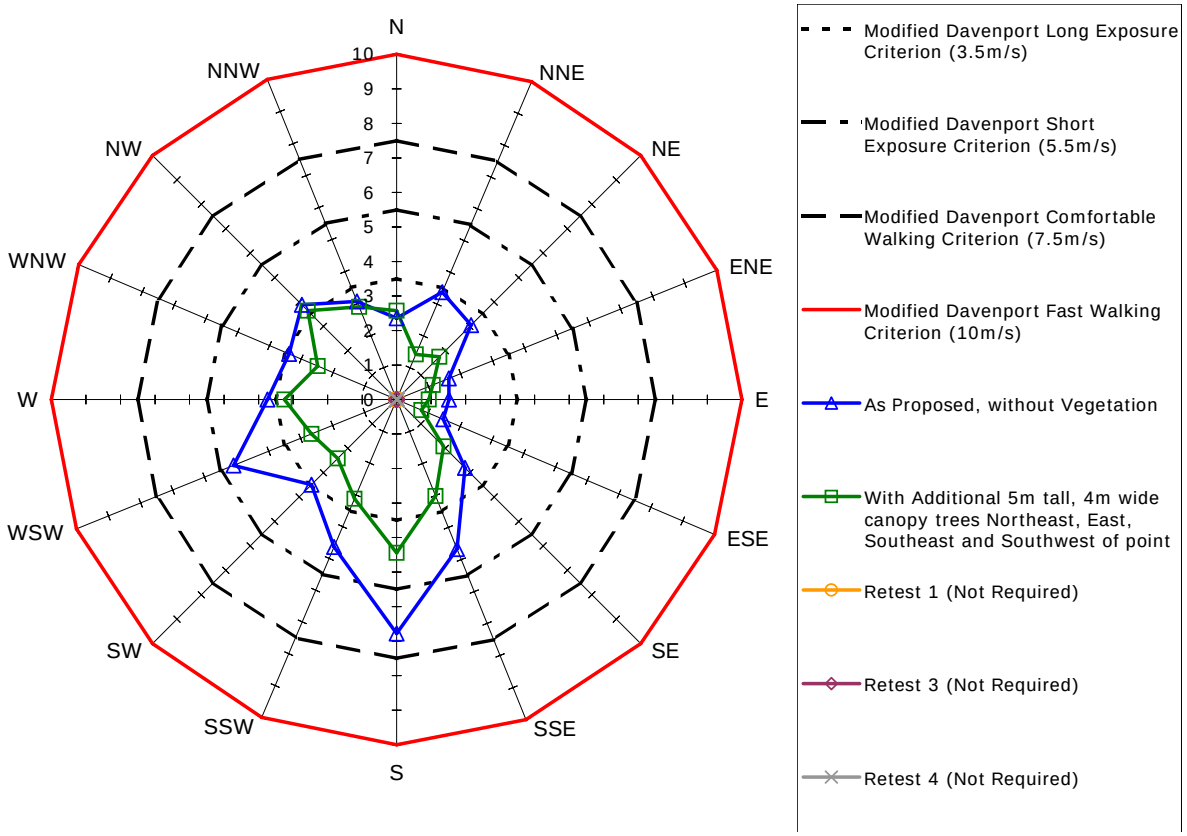


Annual Maximum Gust Wind Speeds (m/s)

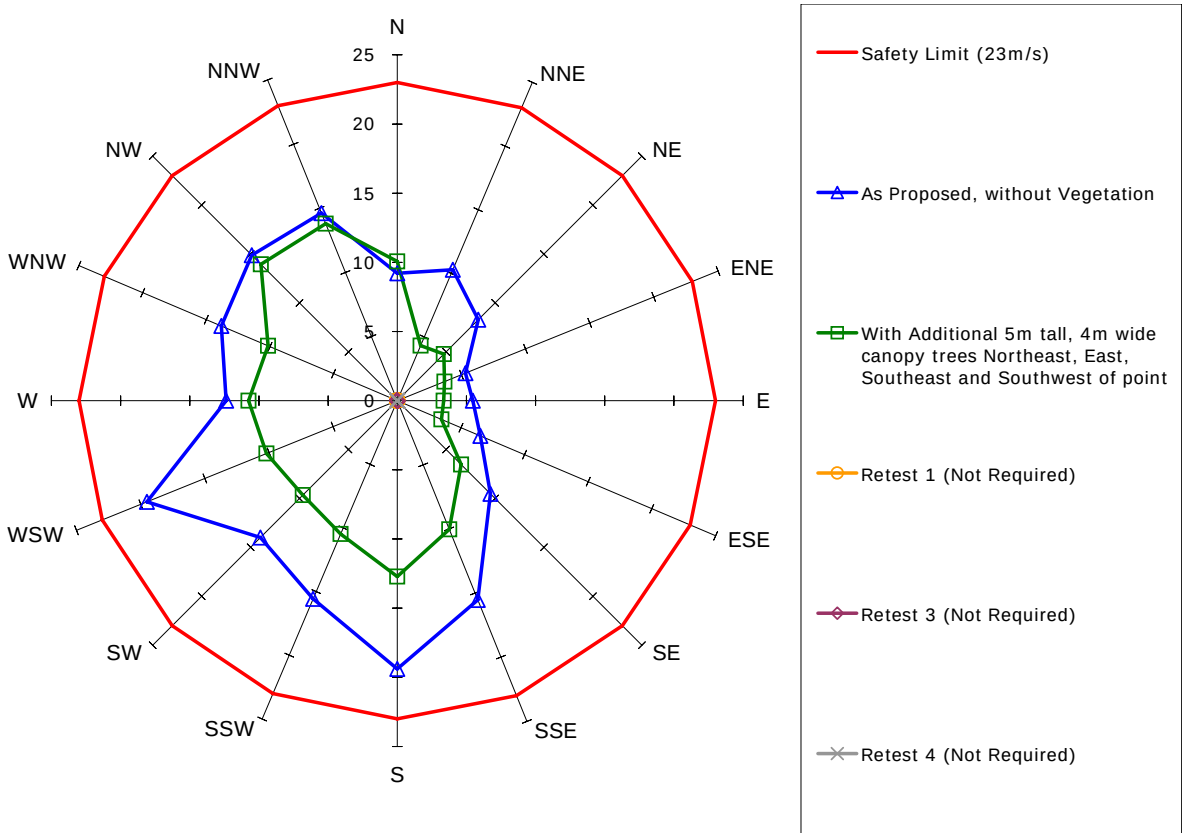


Measured Wind Speeds at Point 16

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

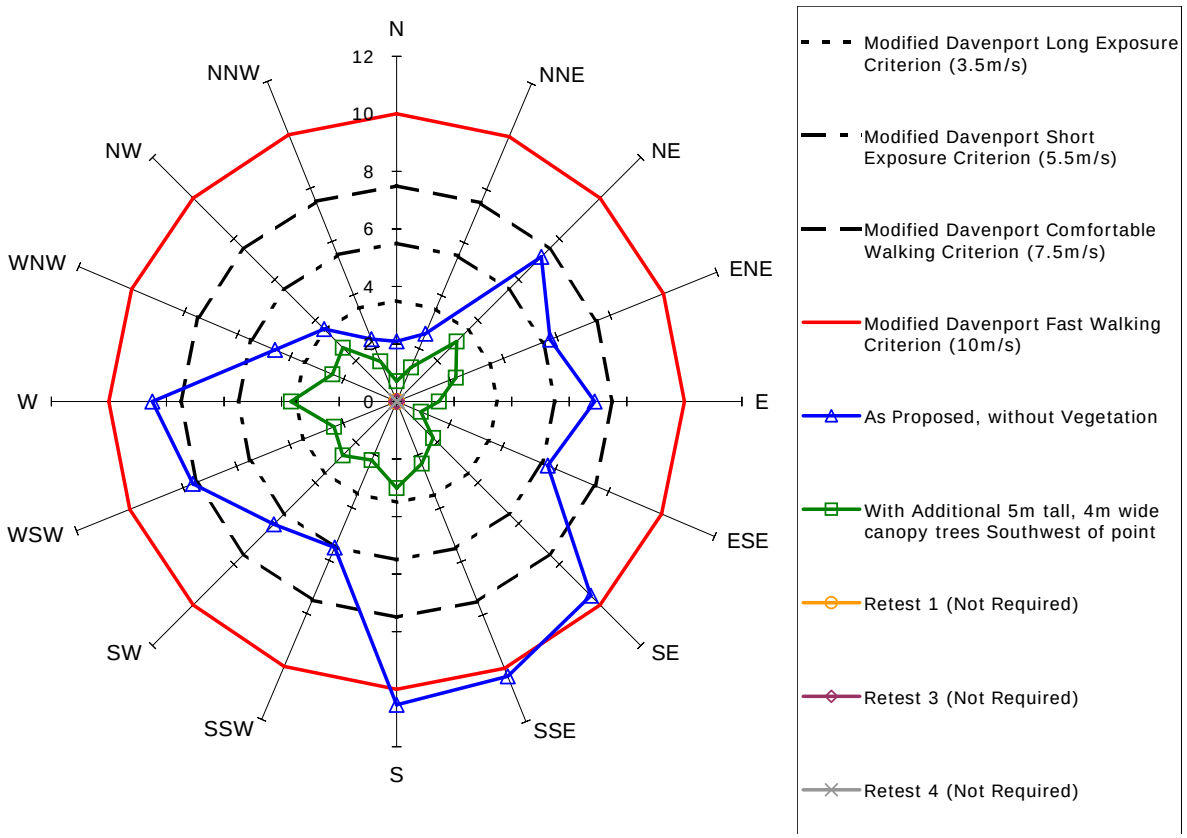


Annual Maximum Gust Wind Speeds (m/s)

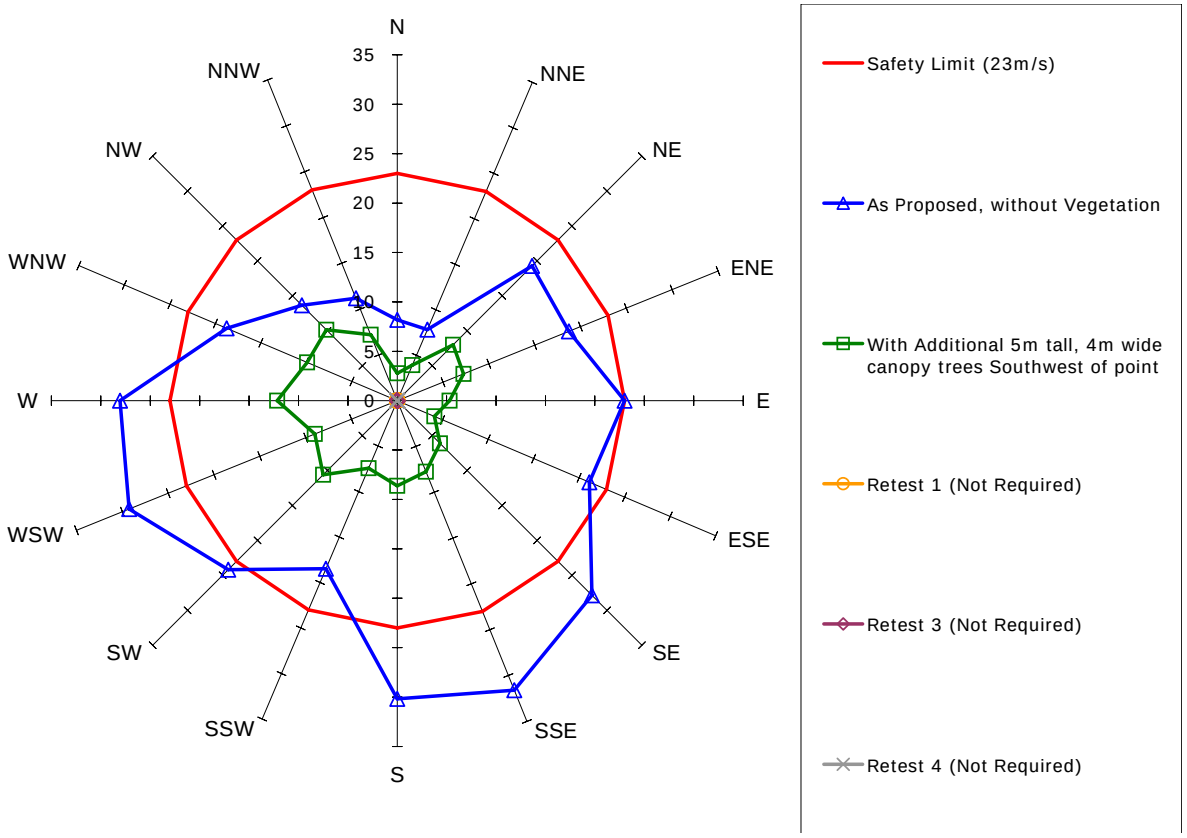


Measured Wind Speeds at Point 17

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

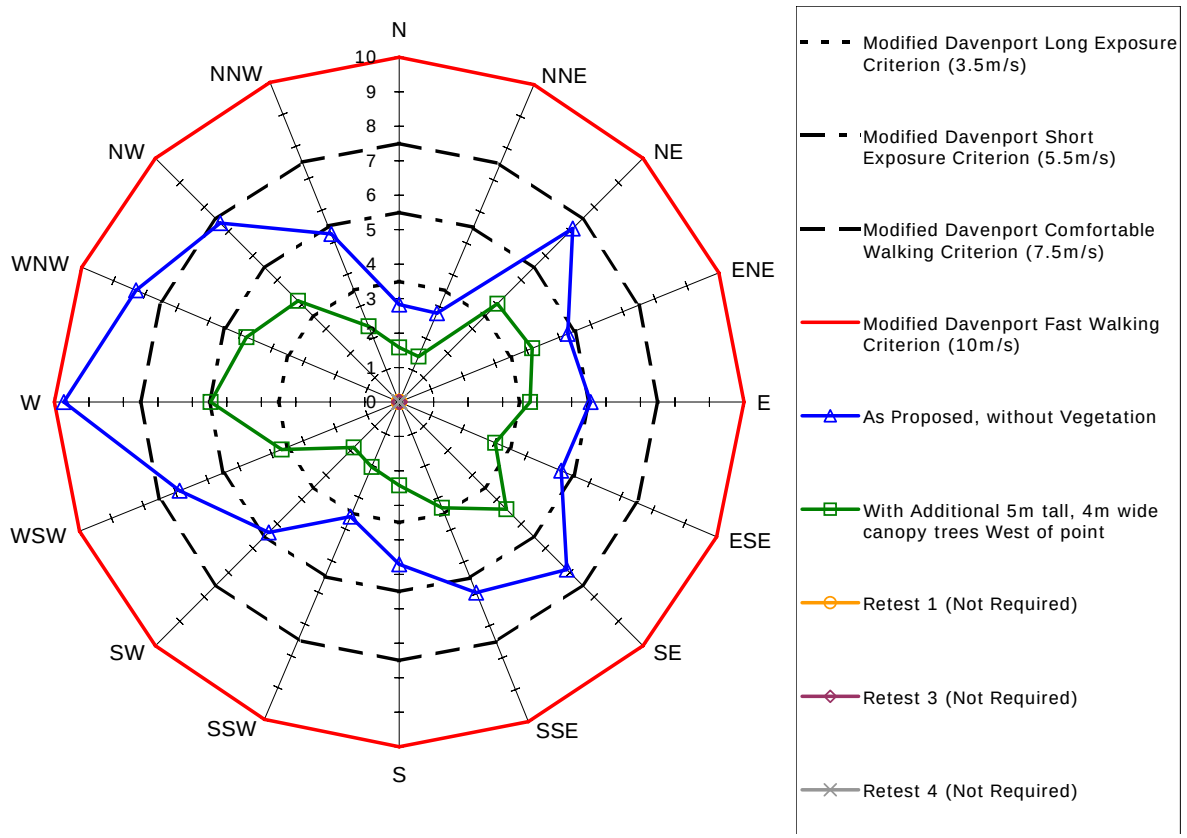


Annual Maximum Gust Wind Speeds (m/s)

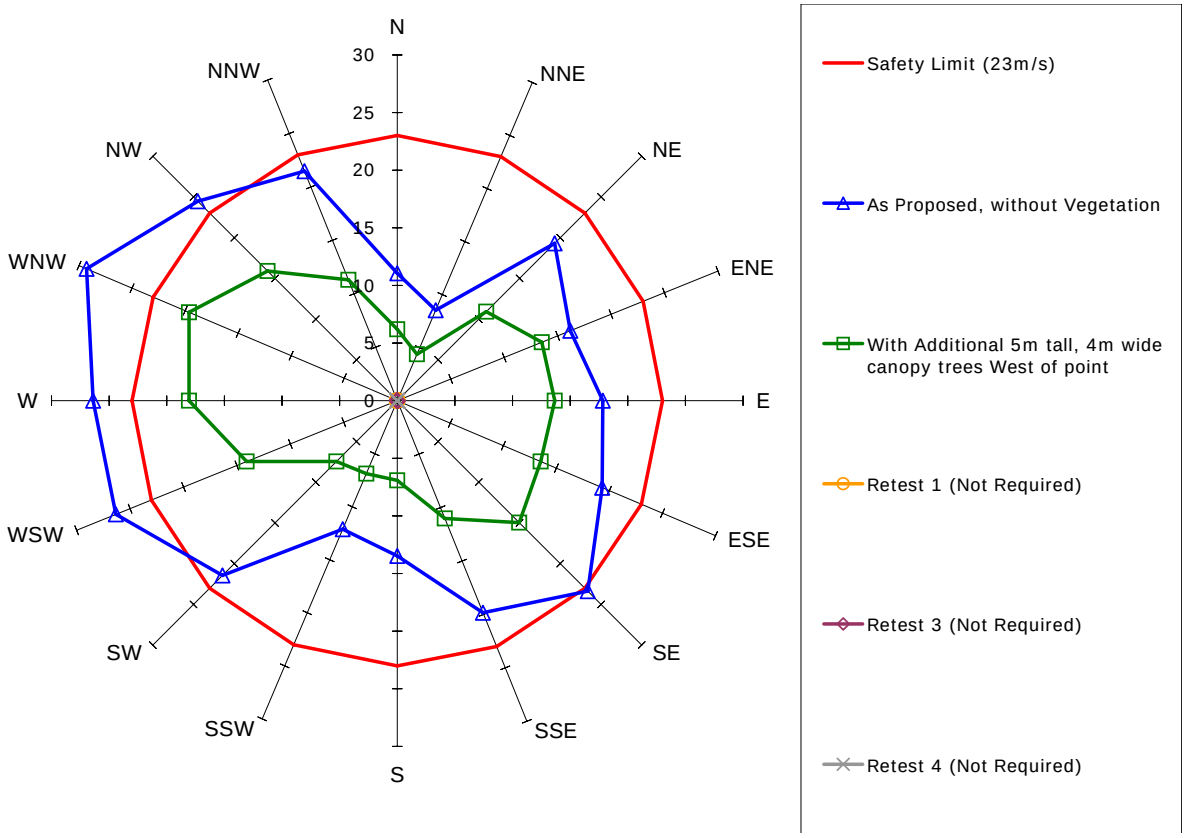


Measured Wind Speeds at Point 18

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

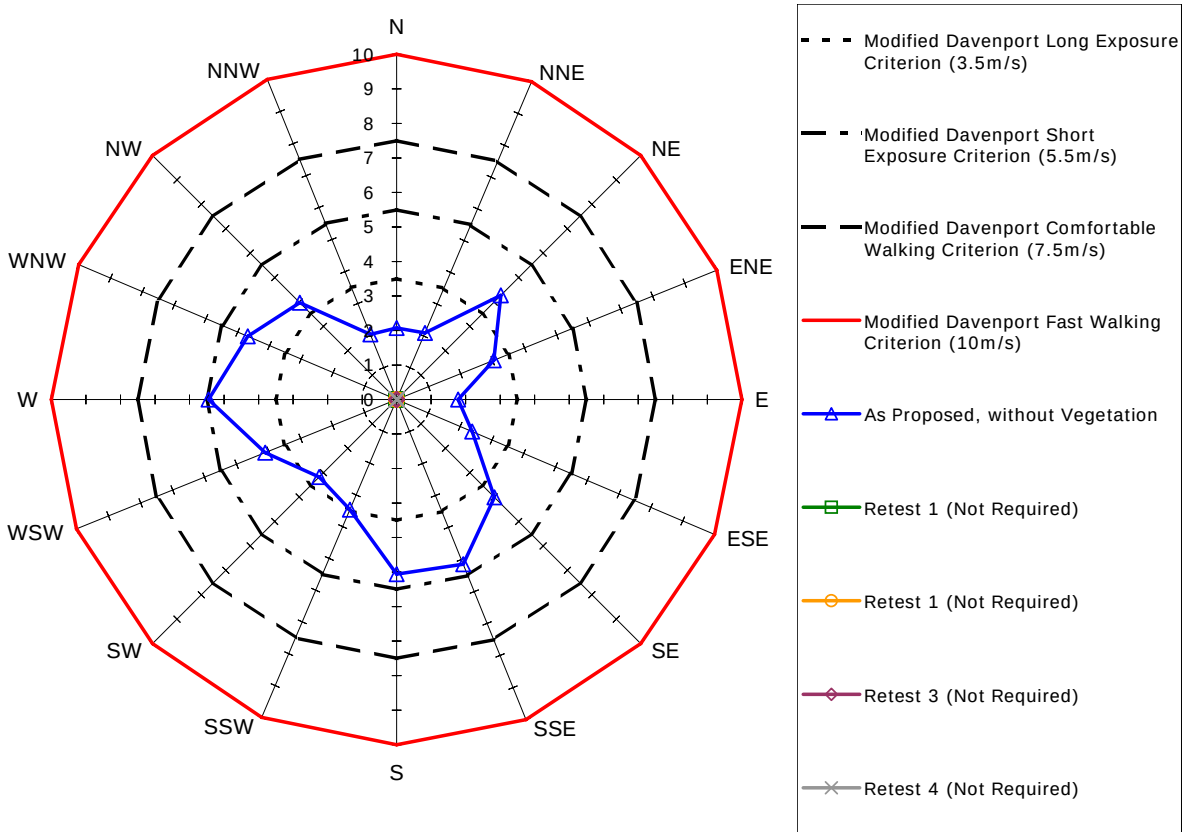


Annual Maximum Gust Wind Speeds (m/s)

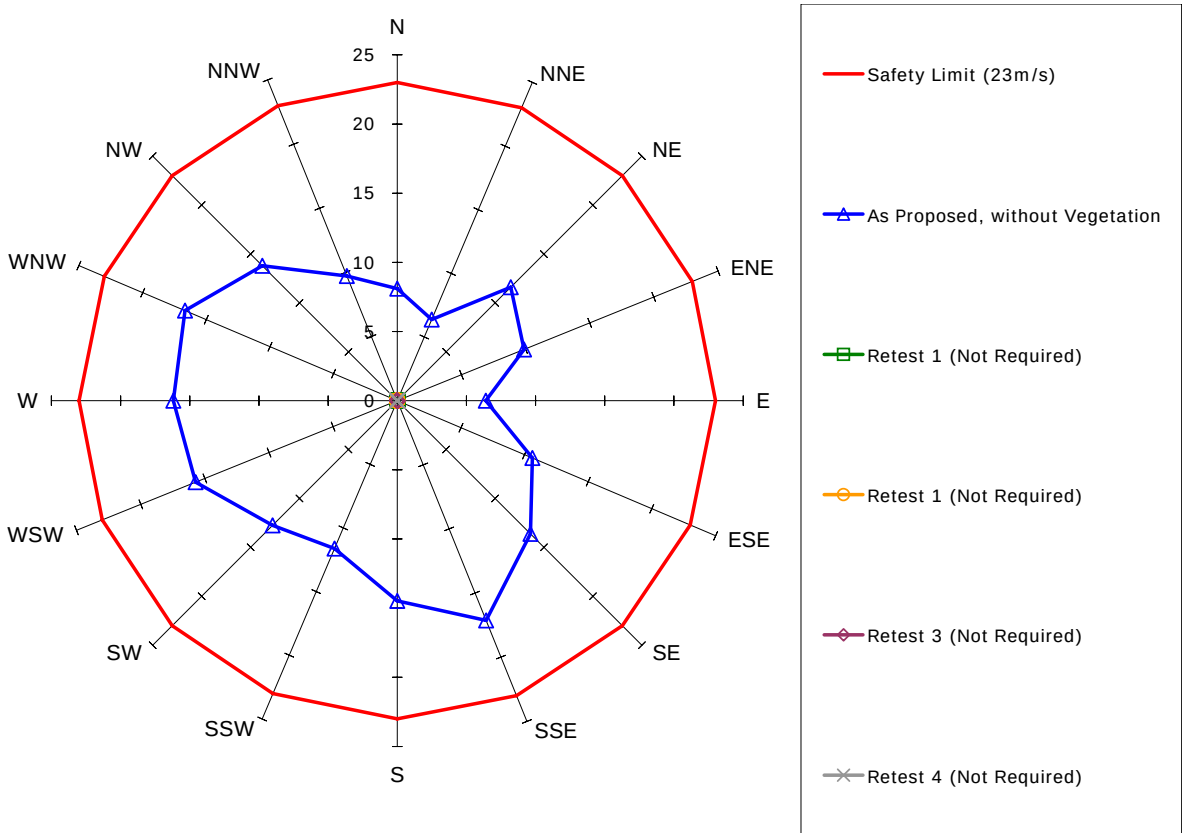


Measured Wind Speeds at Point 19

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

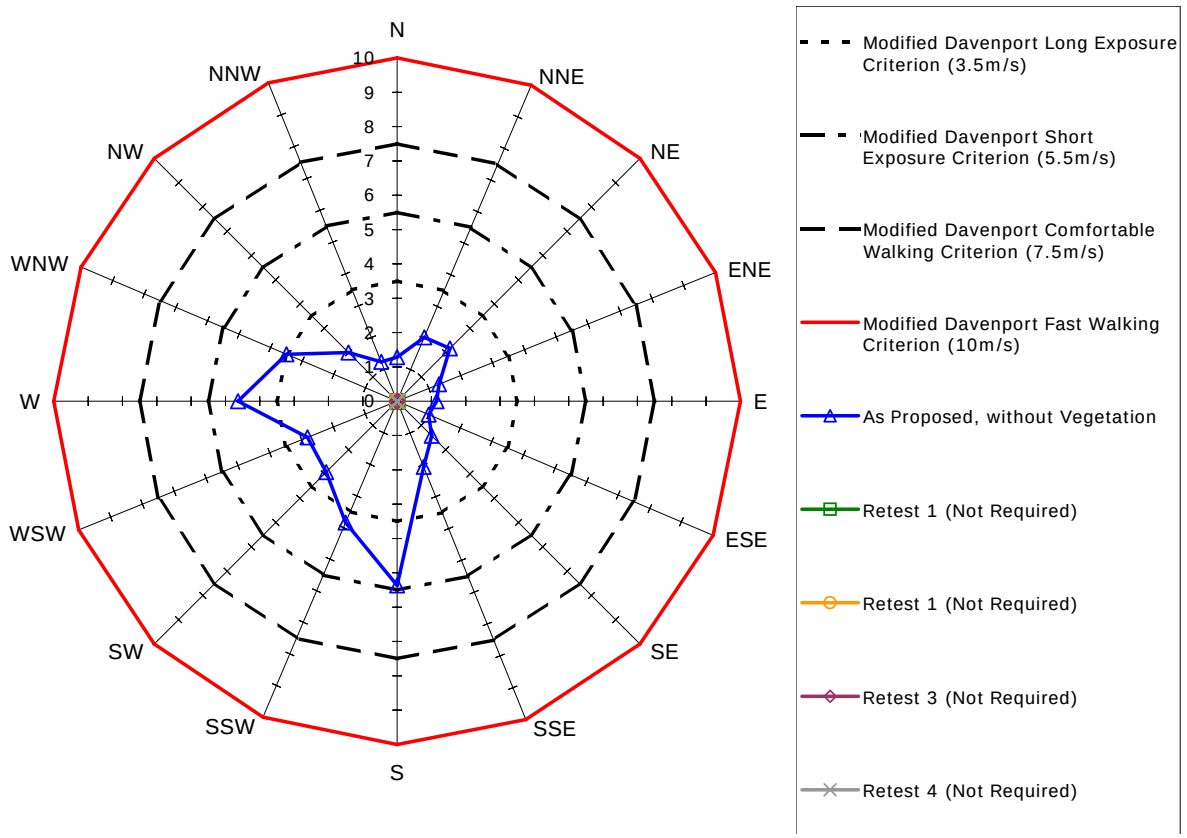


Annual Maximum Gust Wind Speeds (m/s)

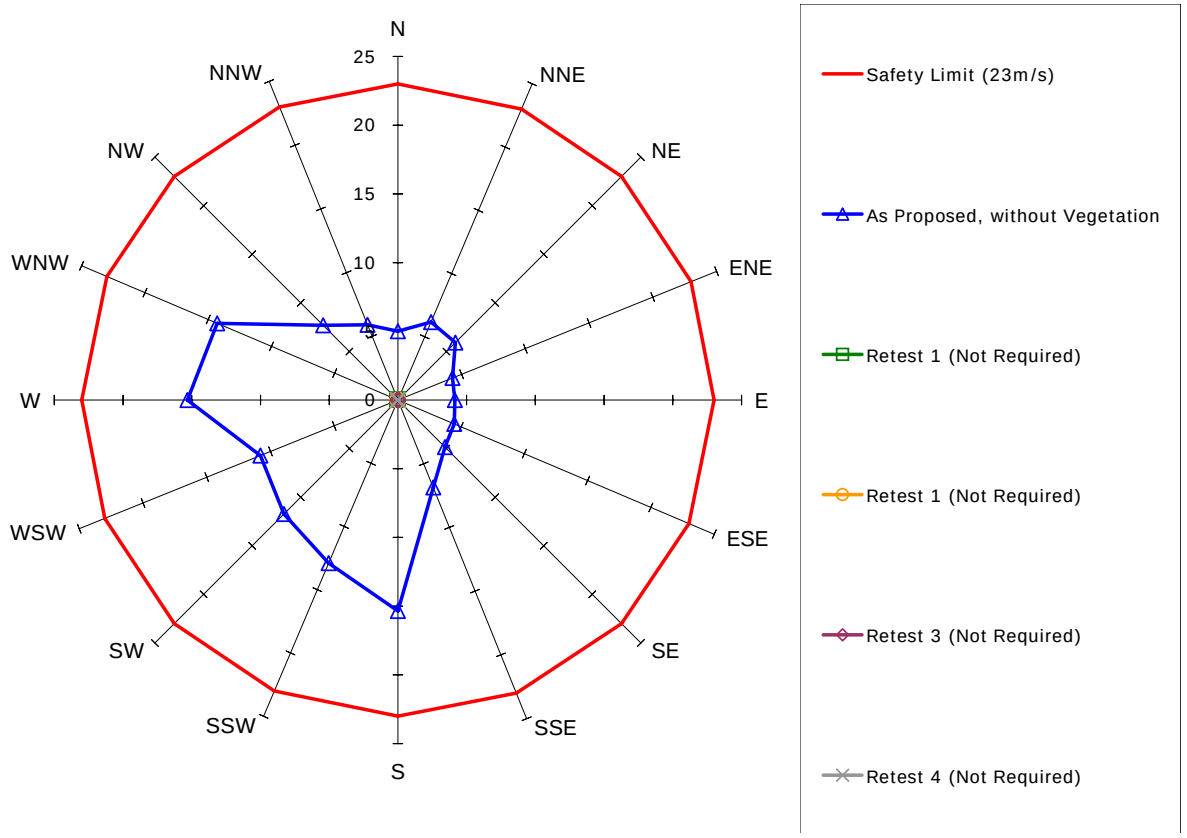


Measured Wind Speeds at Point 20

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

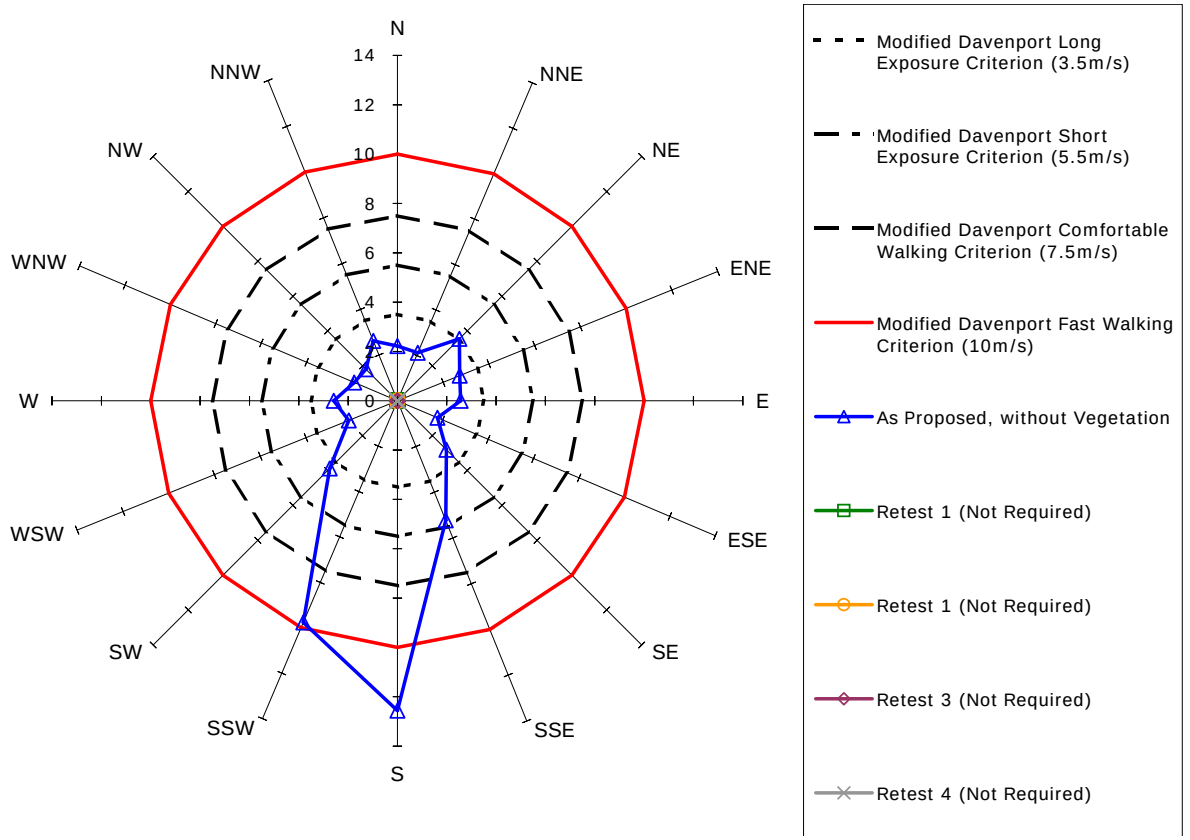


Annual Maximum Gust Wind Speeds (m/s)

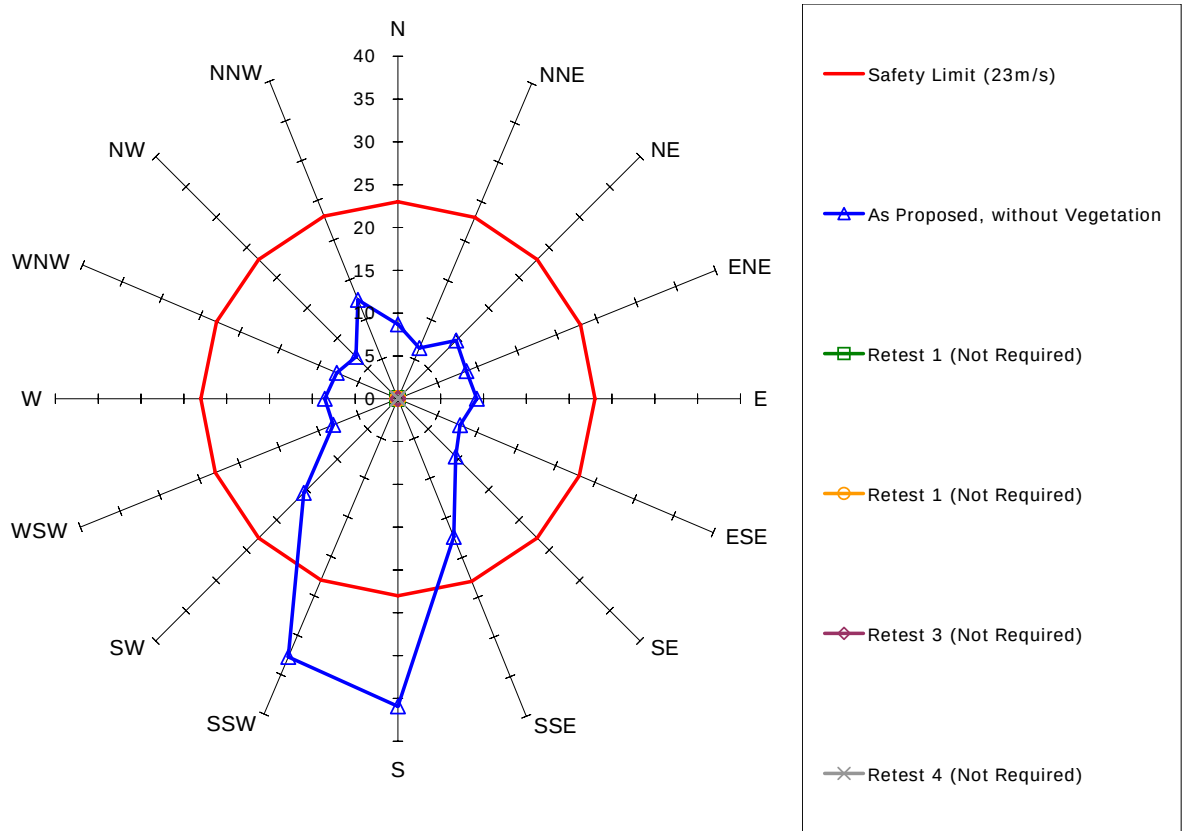


Measured Wind Speeds at Point 21

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

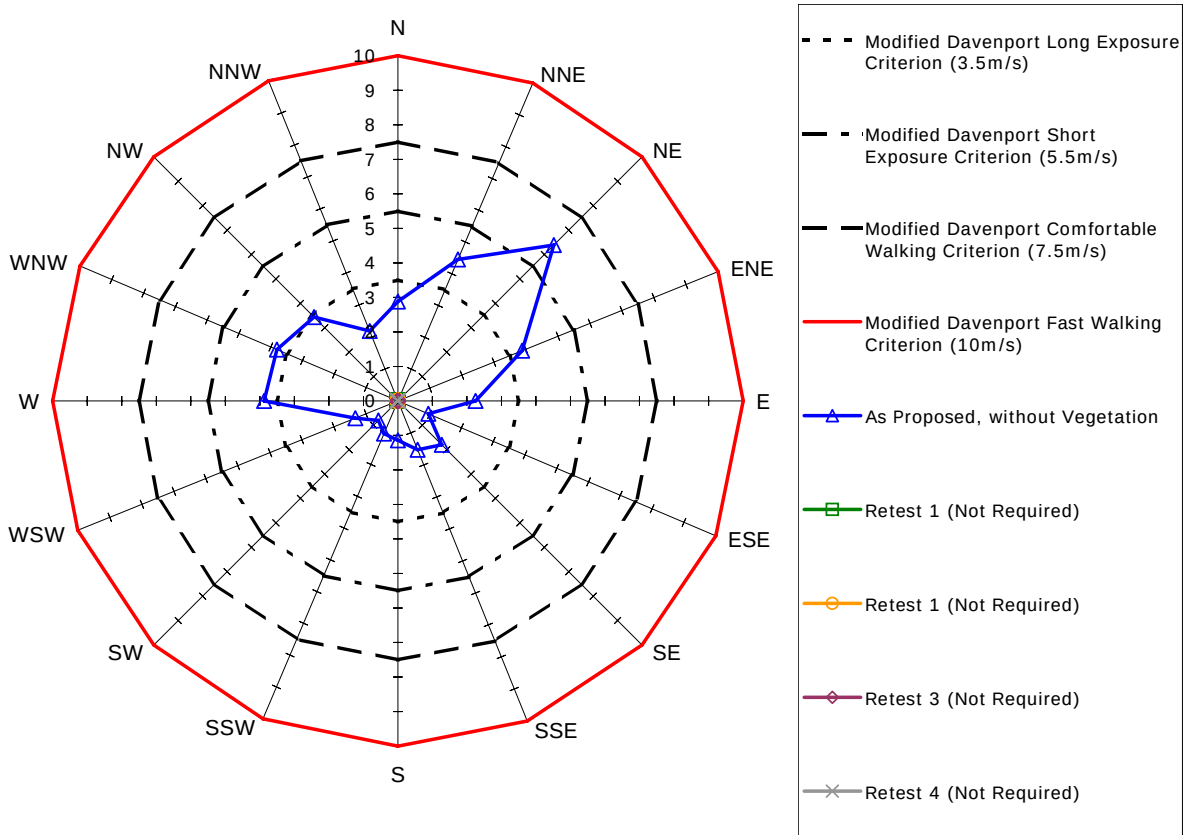


Annual Maximum Gust Wind Speeds (m/s)

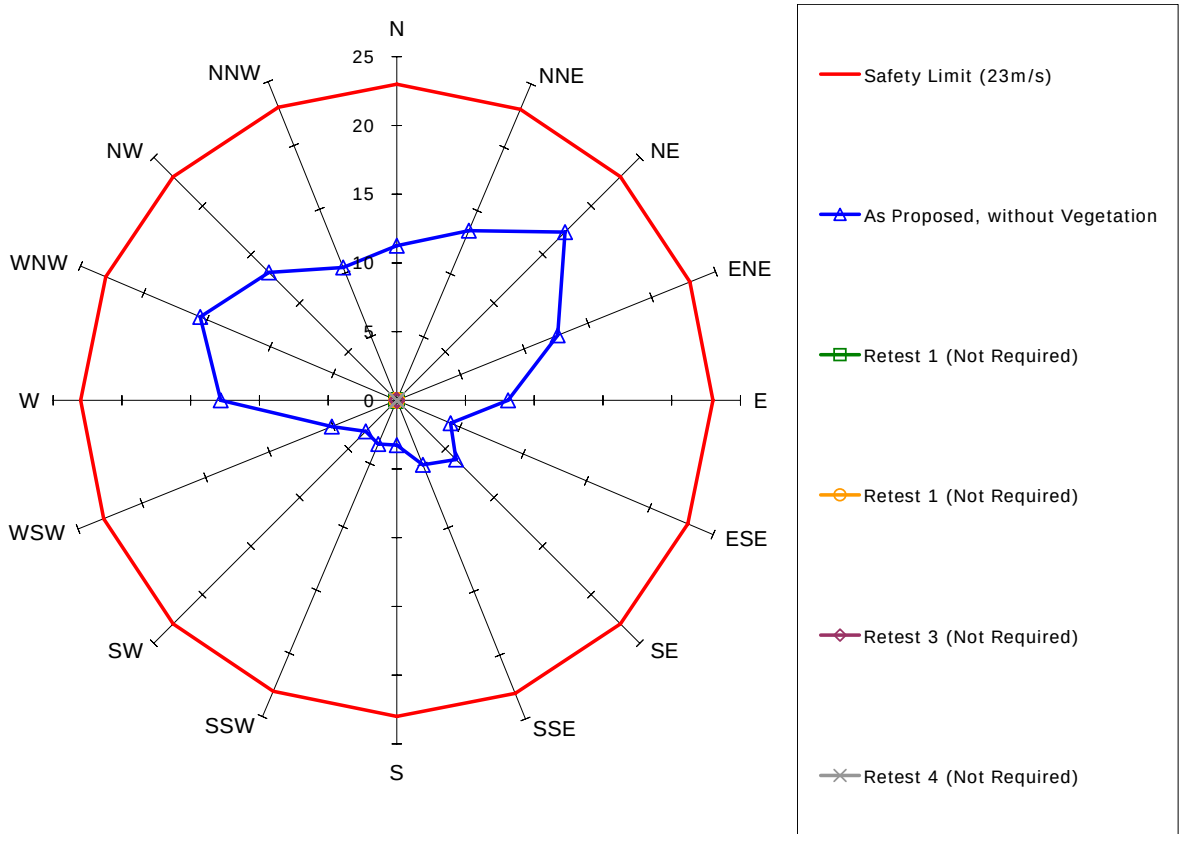


Measured Wind Speeds at Point 22

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

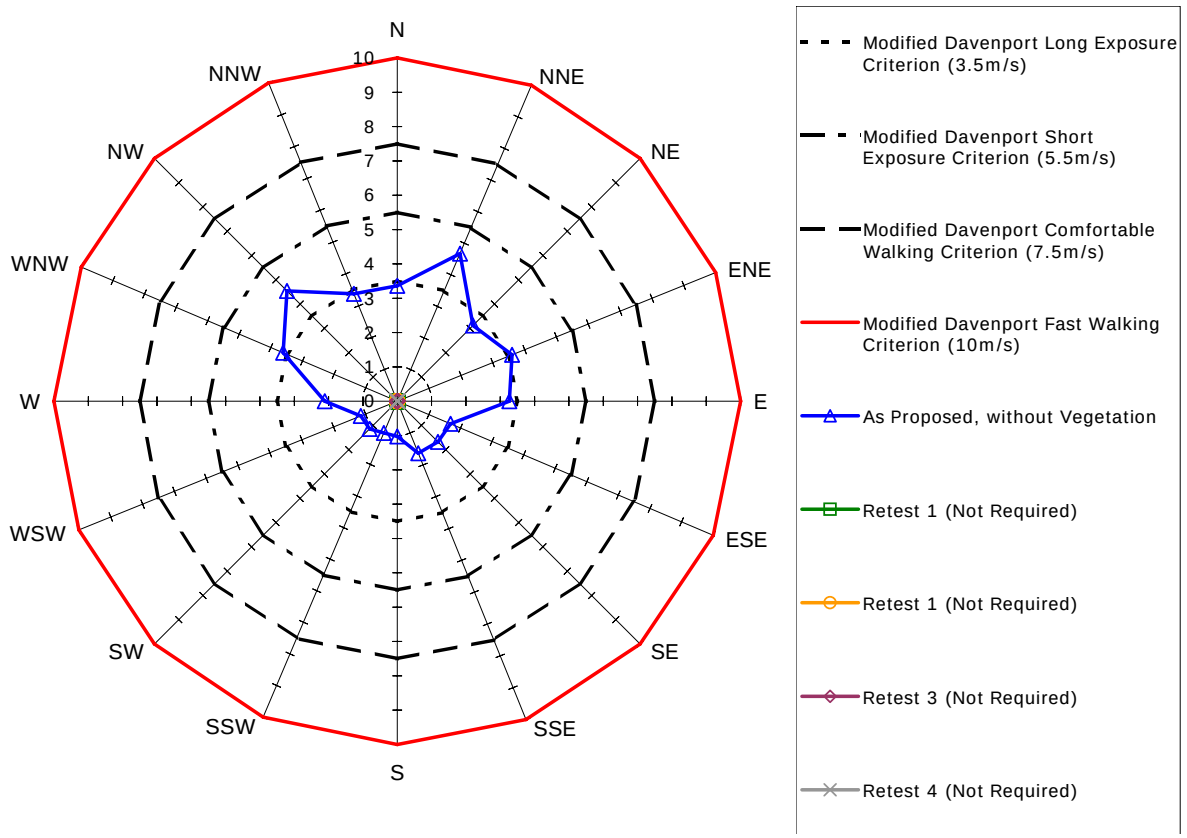


Annual Maximum Gust Wind Speeds (m/s)

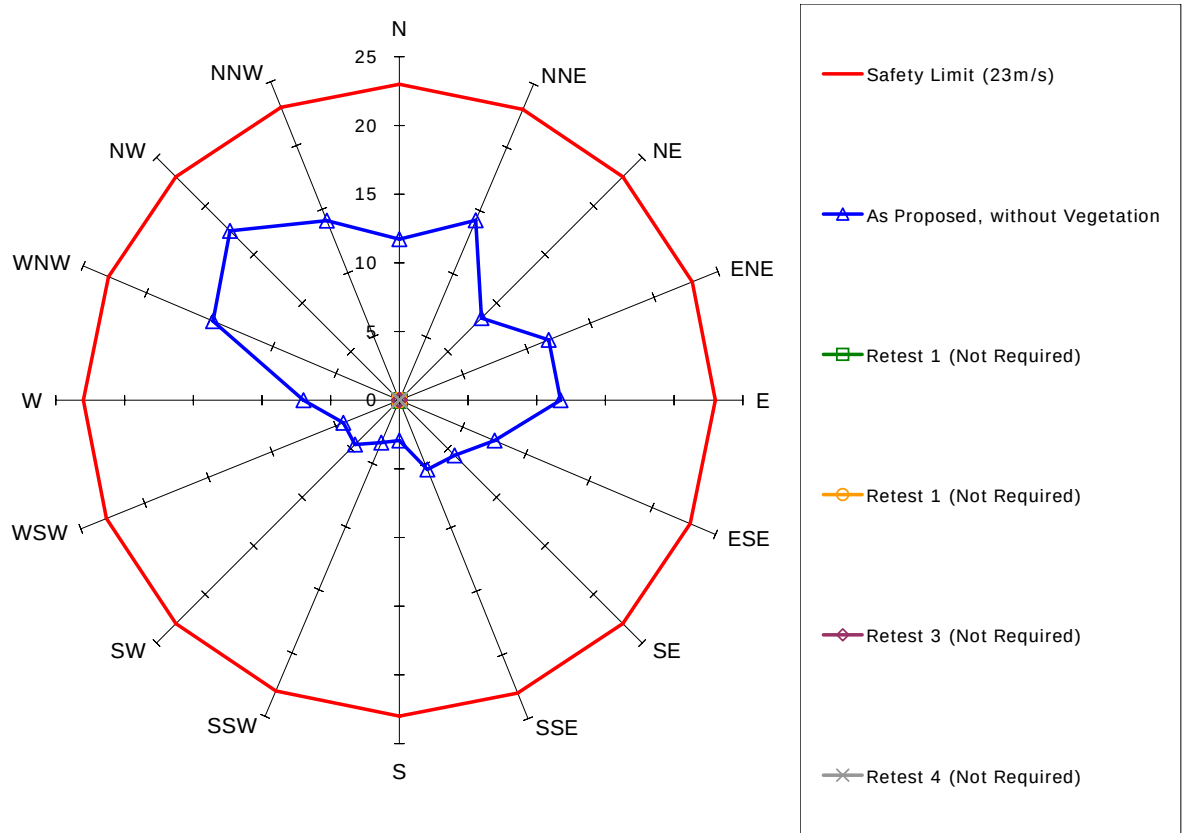


Measured Wind Speeds at Point 23

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

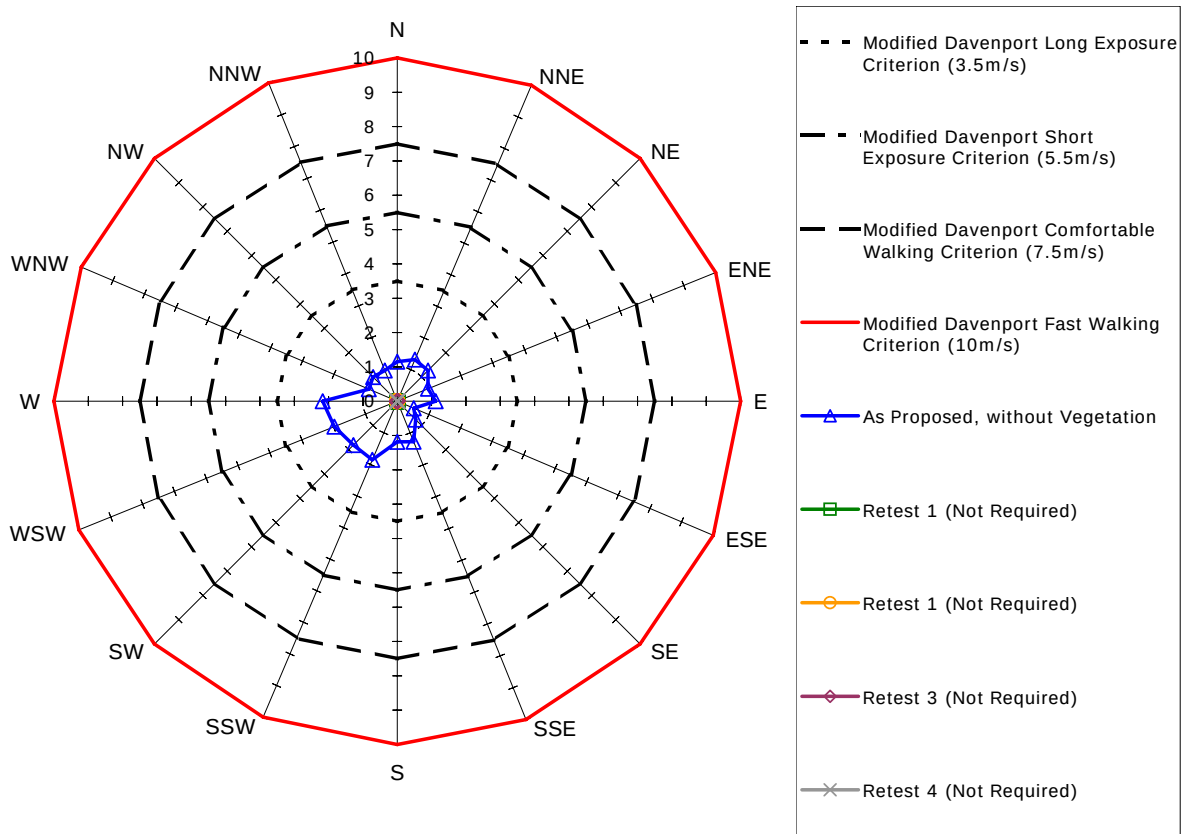


Annual Maximum Gust Wind Speeds (m/s)

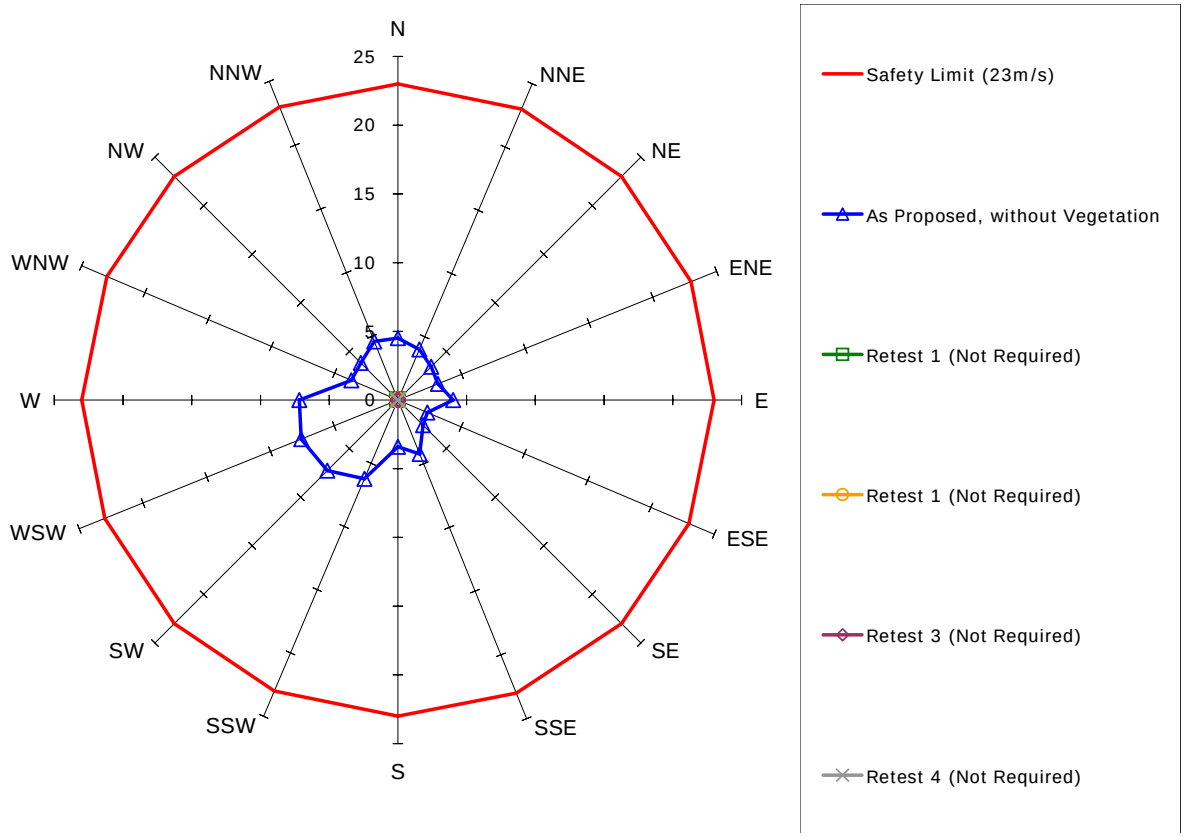


Measured Wind Speeds at Point 24

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

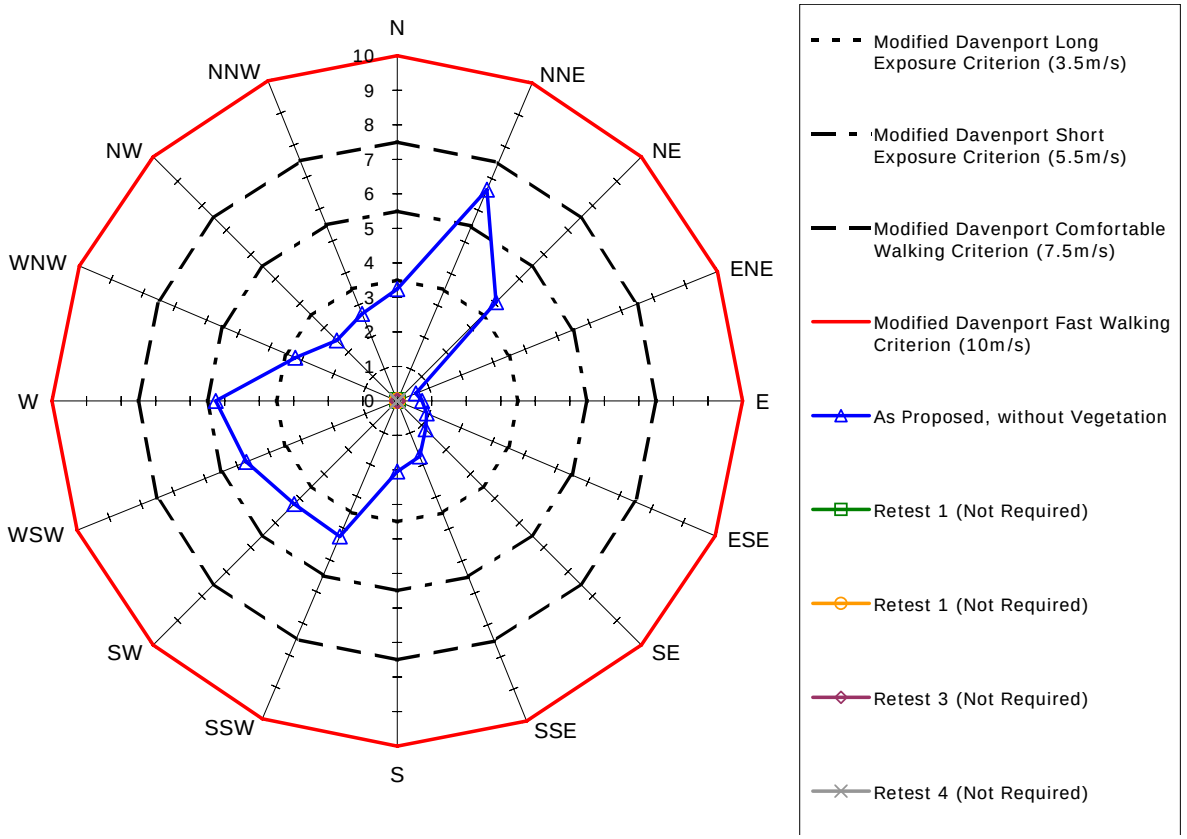


Annual Maximum Gust Wind Speeds (m/s)

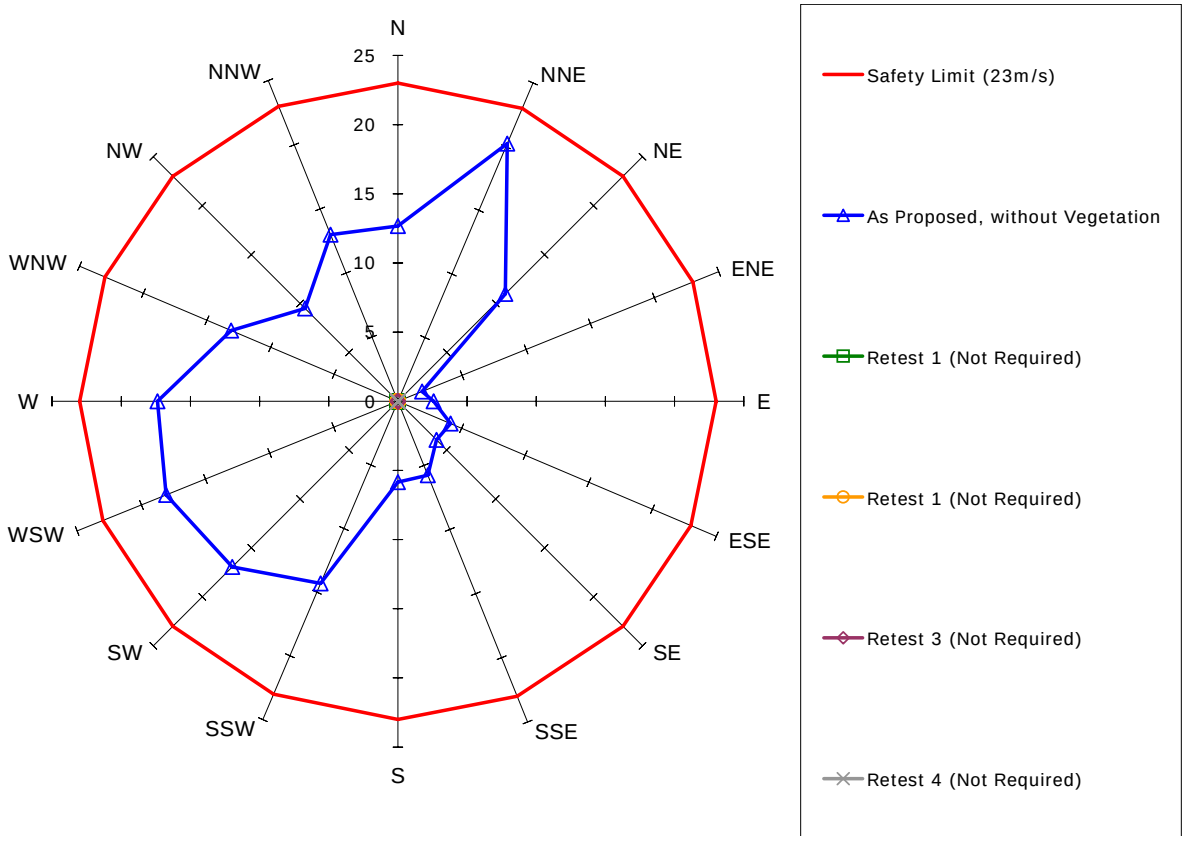


Measured Wind Speeds at Point 25

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

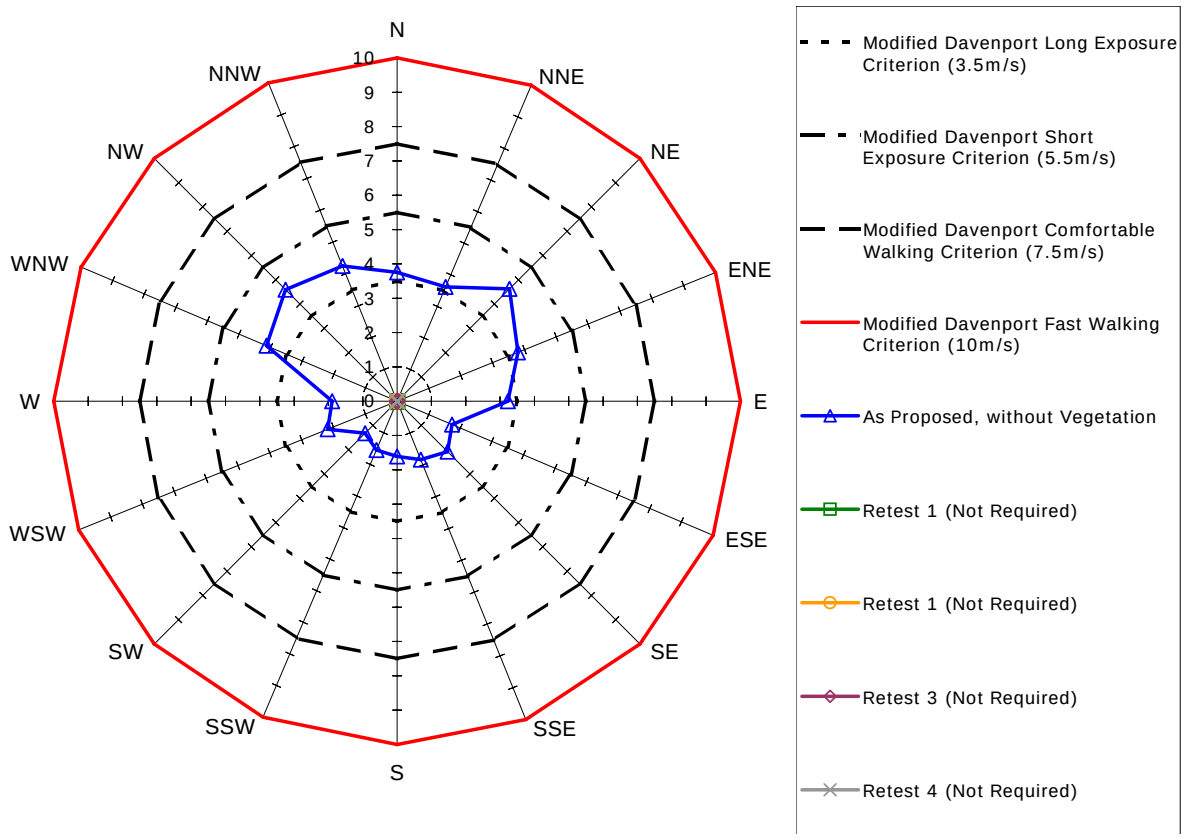


Annual Maximum Gust Wind Speeds (m/s)

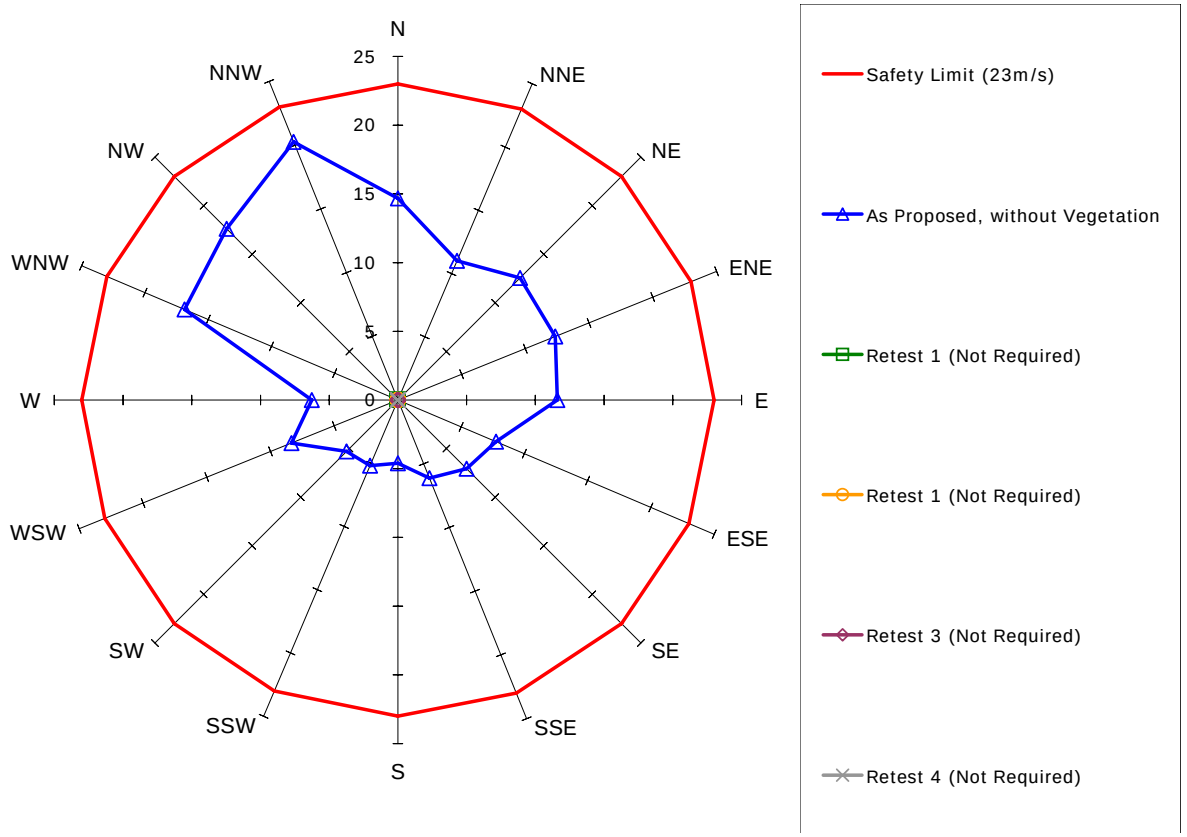


Measured Wind Speeds at Point 26

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

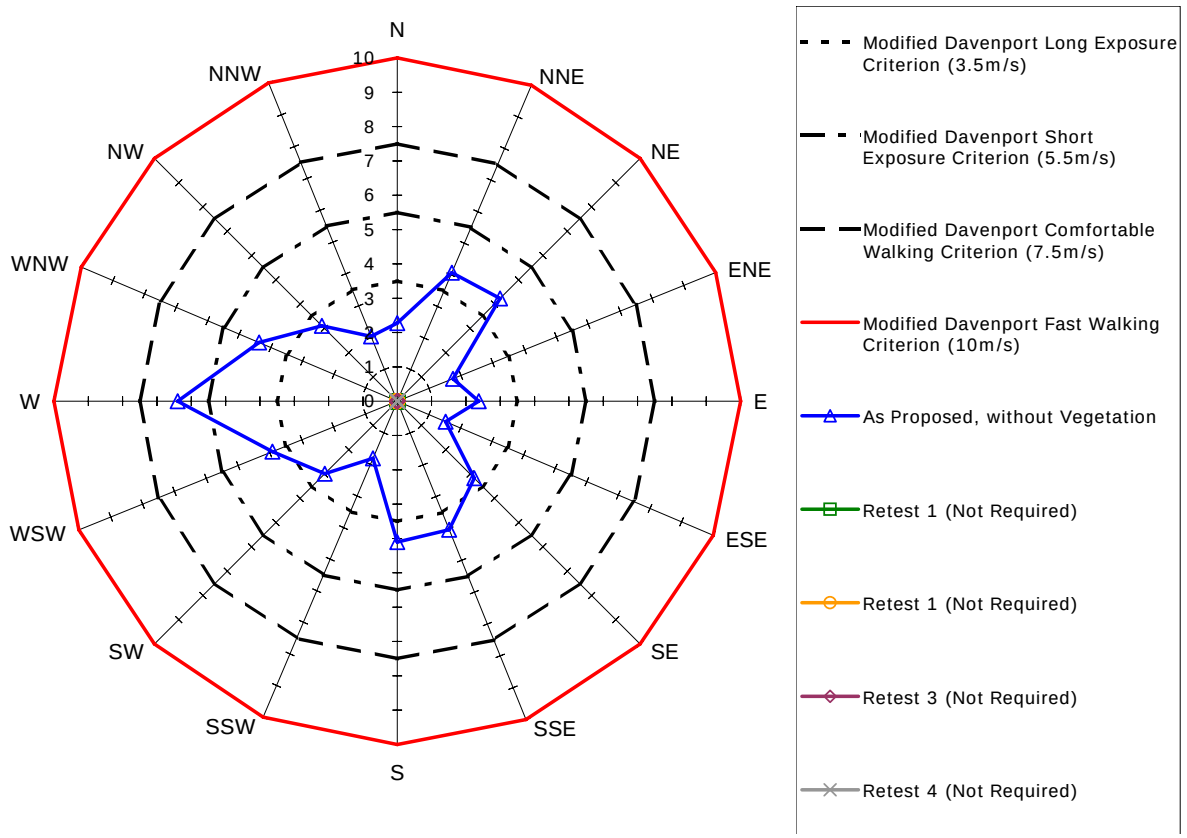


Annual Maximum Gust Wind Speeds (m/s)

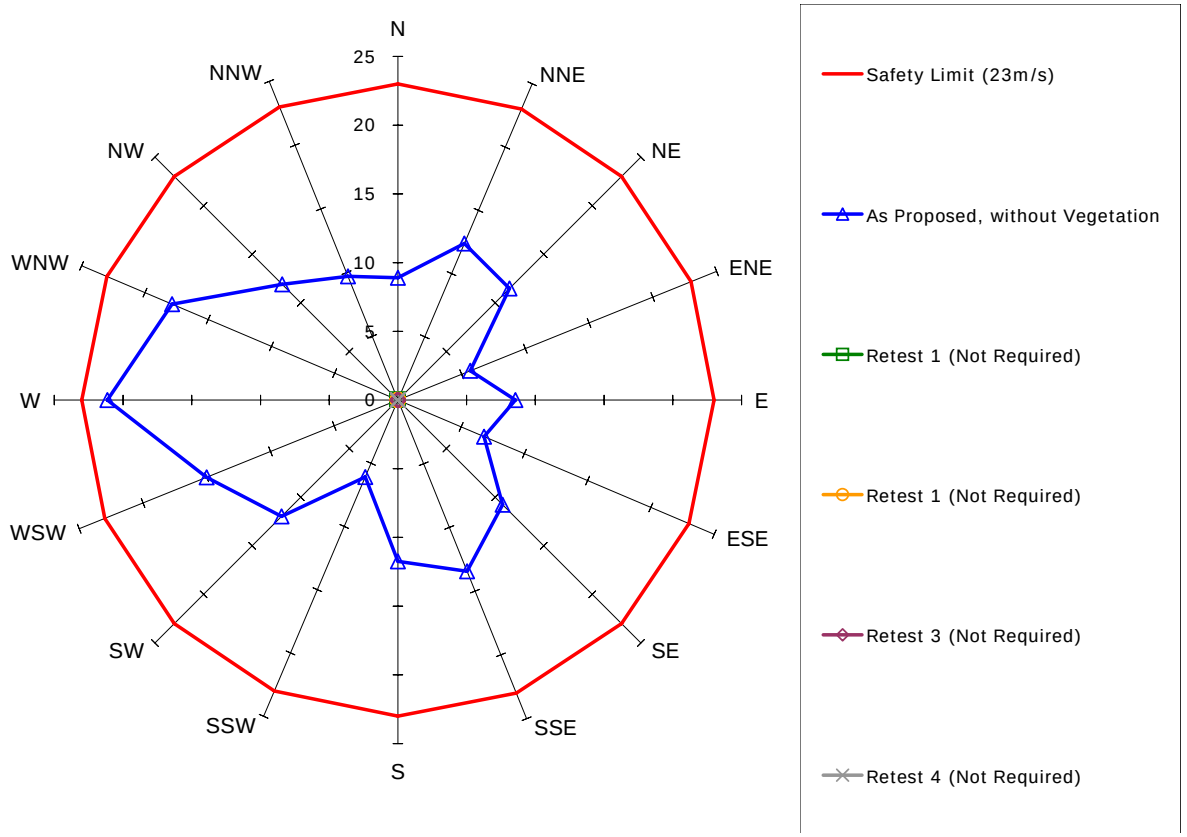


Measured Wind Speeds at Point 27

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

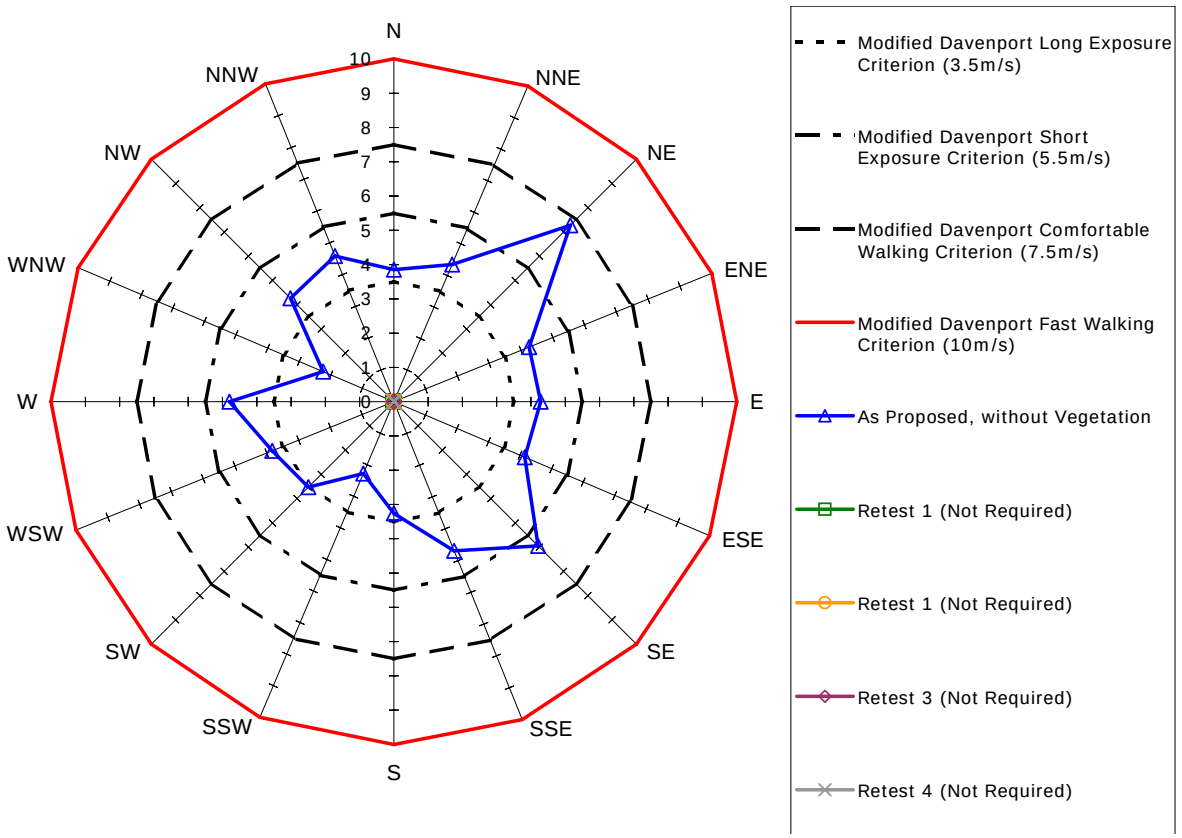


Annual Maximum Gust Wind Speeds (m/s)

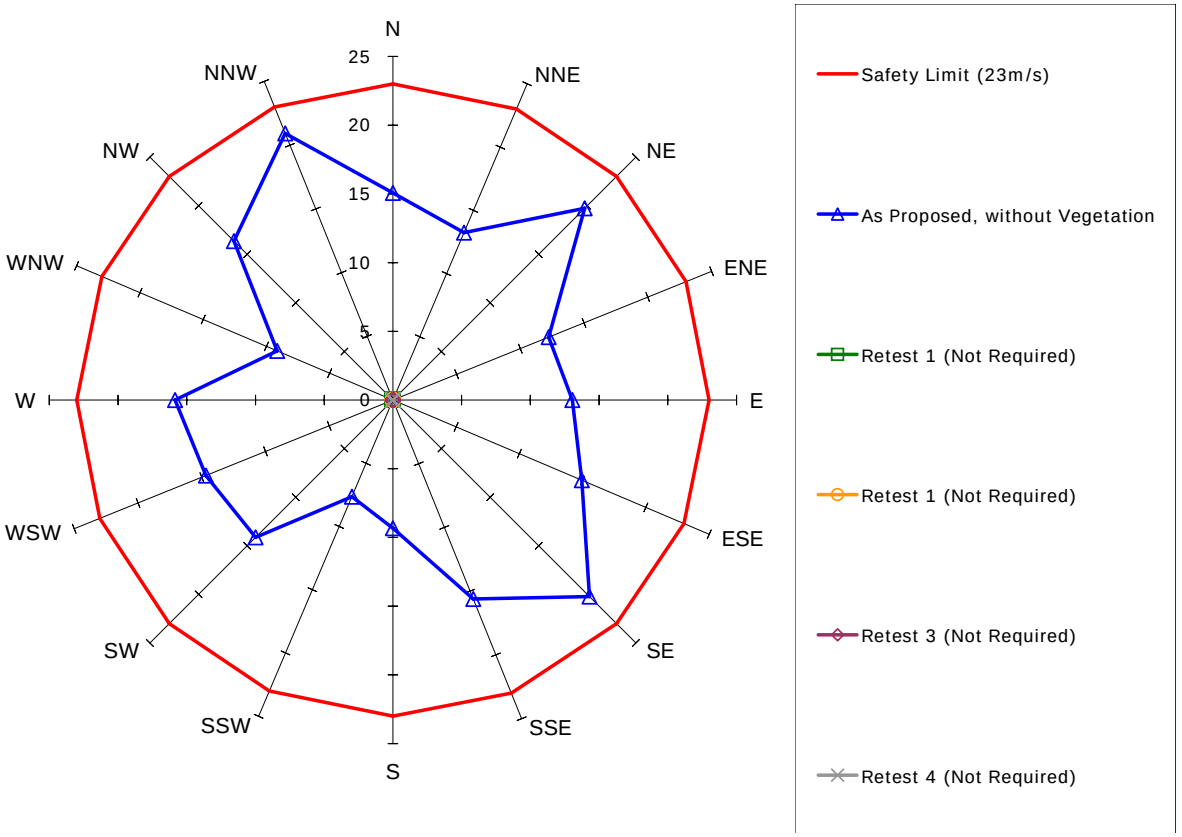


Measured Wind Speeds at Point 28

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

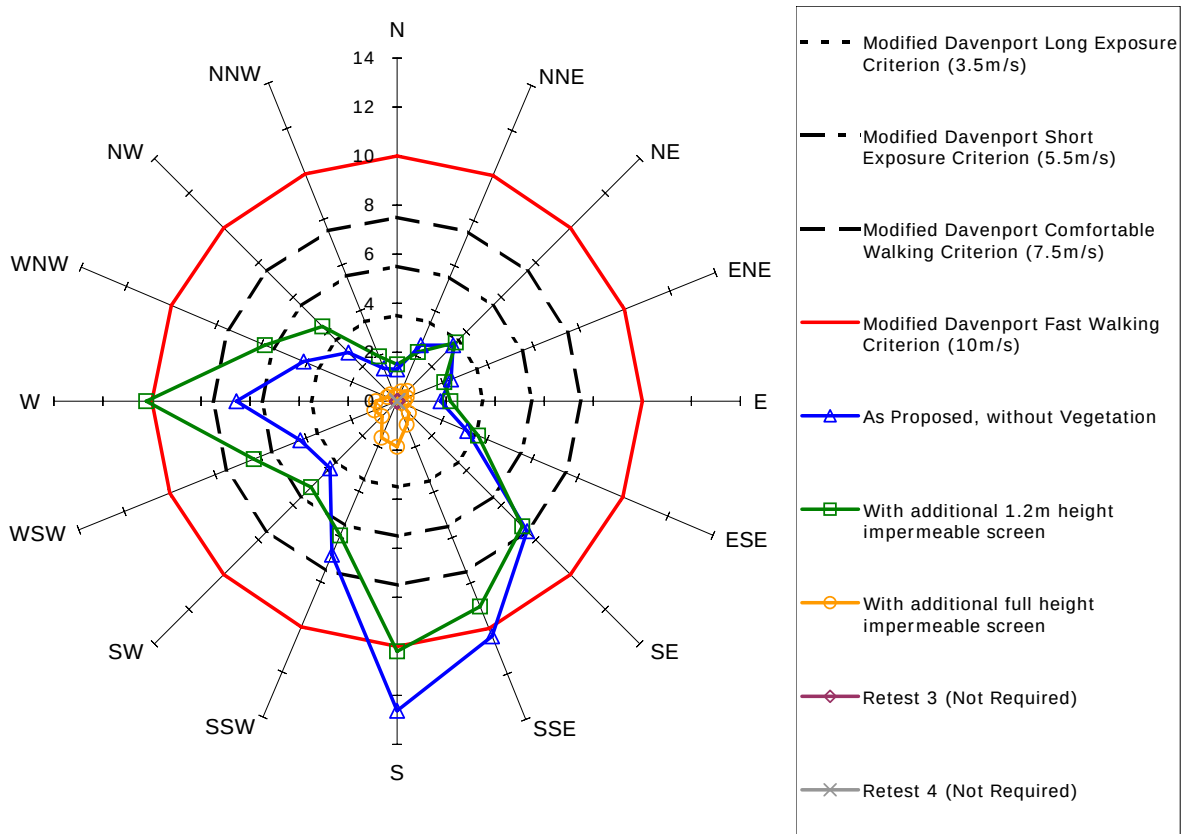


Annual Maximum Gust Wind Speeds (m/s)

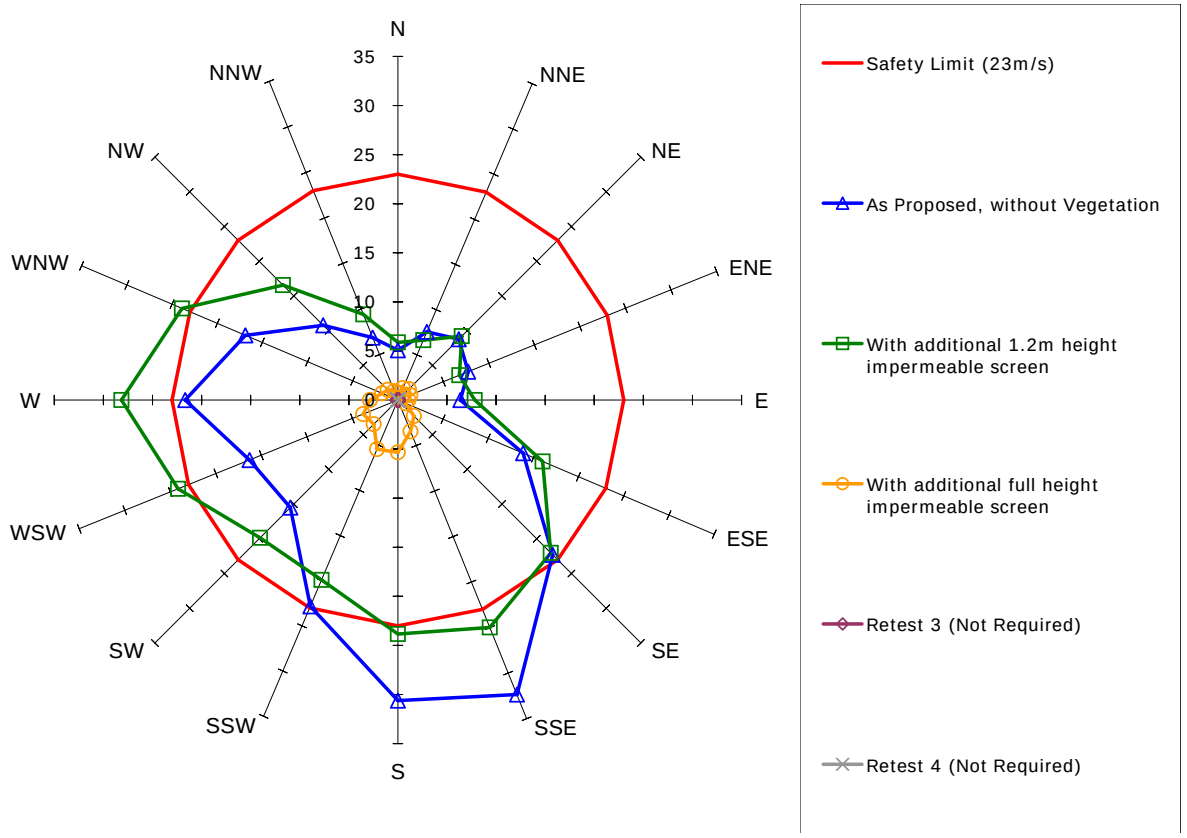


Measured Wind Speeds at Point 29

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

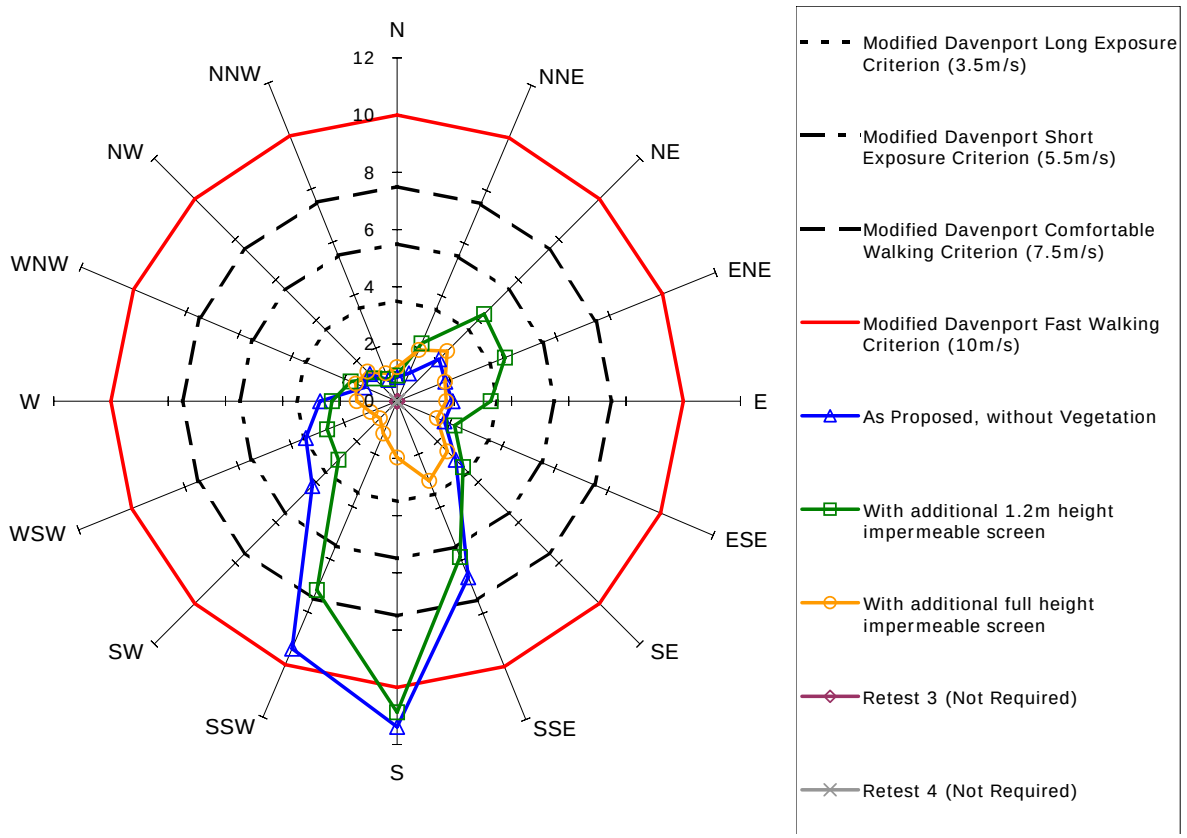


Annual Maximum Gust Wind Speeds (m/s)

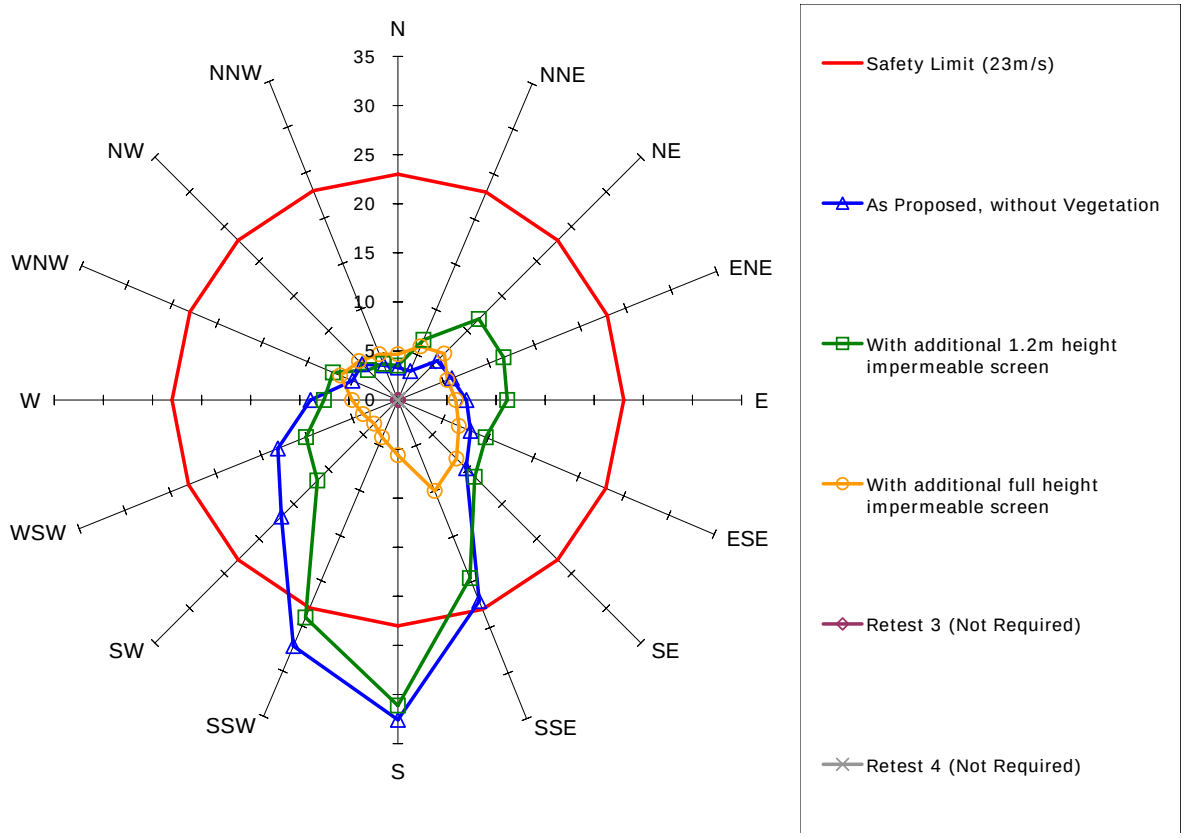


Measured Wind Speeds at Point 30

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

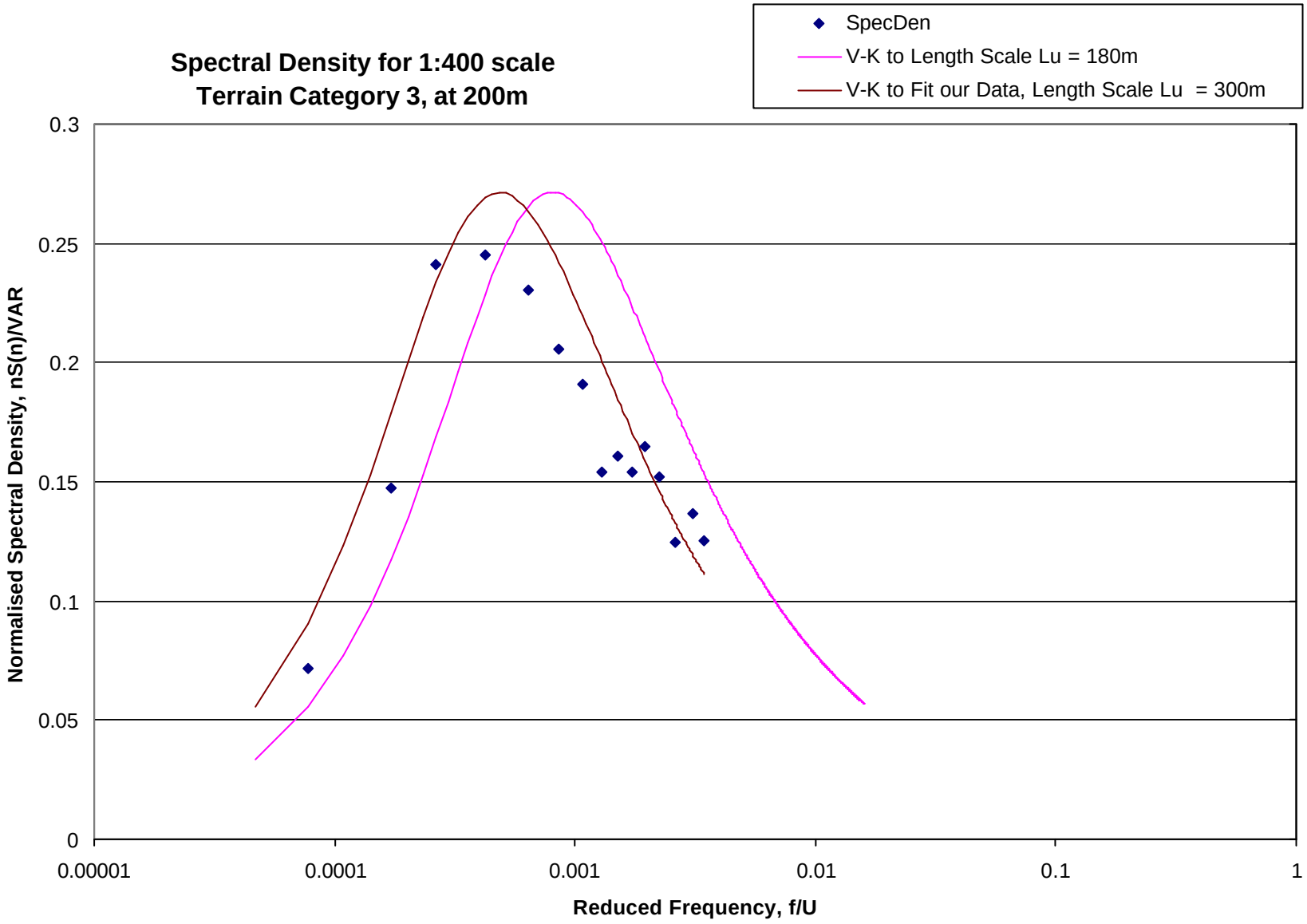


Annual Maximum Gust Wind Speeds (m/s)



Appendix C

Wind Tunnel Boundary Layer Profiles


Spectral Density for 1:400 scale
Terrain Category 3, at 200m
SpecDen
V-K to Length Scale Lu = 180m
V-K to Fit our Data, Length Scale Lu = 300m
Normalised Spectral Density, nS(n)/VAR
0.3
0.25
0.2
0.15
0.1
0.05
0
0.00001
0.0001
0.001
0.01
0.1
1
Reduced Frequency, f/U

Velocity and Turbulence Profiles, 1:400 Scale, Terrain Category 3